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Conservation
Research
Report Number 38

September 1994

Crop Residue Management To Reduce Erosion and Improve Soil Quality

Northern Great Plains

Historic, archived document

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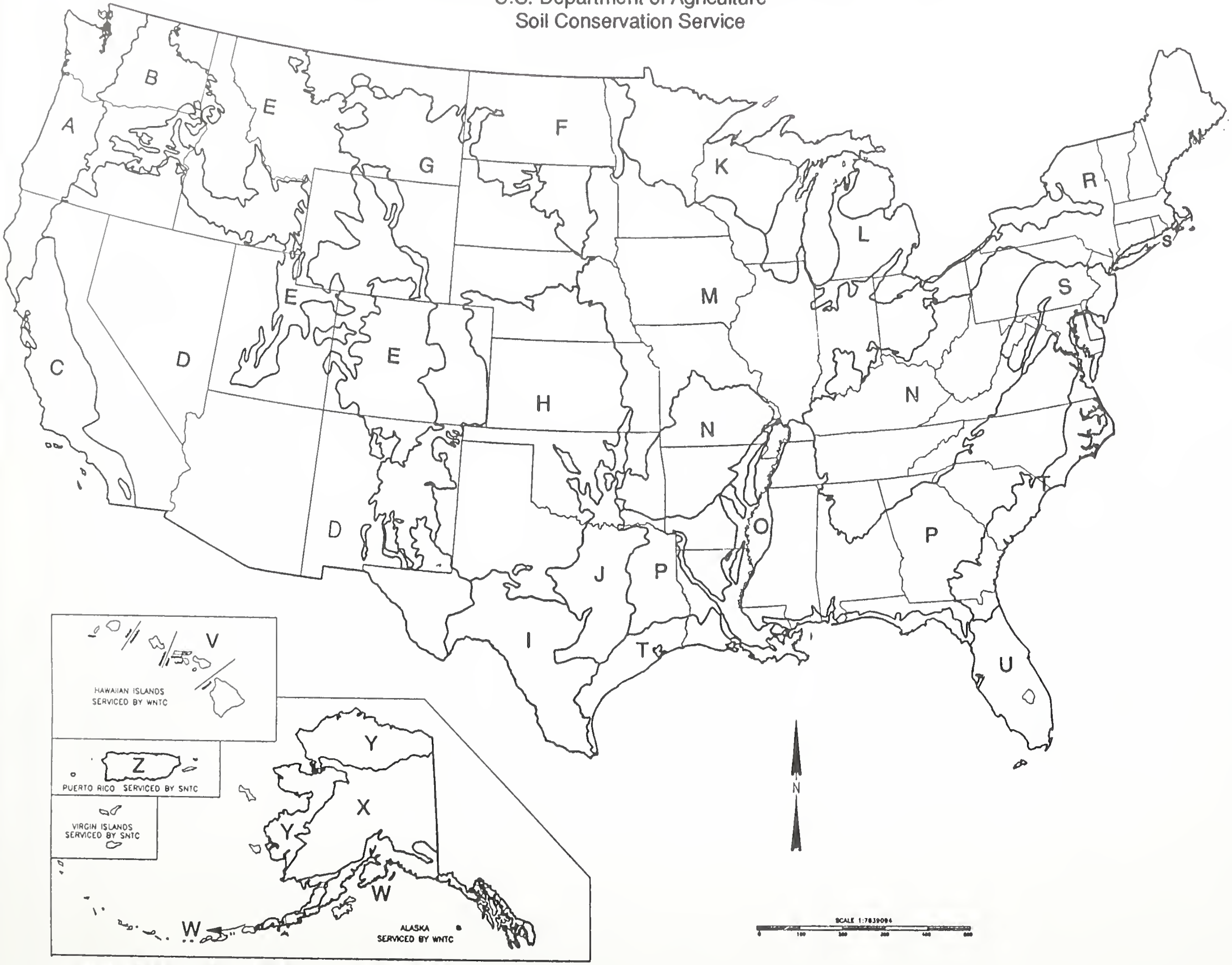
Crop Residue Management
Land Resource Regions of the United States

U.S. Department of Agriculture
Soil Conservation Service



Source: Map prepared using automated map construction. Albers equal area projection. National Cartography and Geographic Information System Center, Fort Worth, Texas 1993.

Resource Regions and Areas
as of January 1984
Land Resource Regions (LRR)

A	NW Forest, Forage and Specialty Crops
B	NW Wheat and Range
C	California Subtropical Fruit, Truck and Specialty Crops
D	W. Range and Irrigated
E	Rocky Mtn. Range and Forest
F	N. Great Plains Spring Wheat
G	W. Great Plains Range and Irrigated
H	C. Great Plains Winter Wheat and Range
I	SW Plateaus and Plains Range and Cotton
J	SW Prairies Cotton and Forage
K	N. Lake State Forest and Forage
L	Lake States Fruit, Truck and Dairy
M	Central Feed Grains and Livestock
N	East and Central Farming and Forest
O	Miss. Delta Cotton and Feed Grains
P	S. Atlantic and Gulf Slope Cash Crops, Forest and Livestock
R	NE Forage and Forest
S	N. Atlantic Slope Diversified Farming
T	Atlantic and Gulf Coast Lowland Forest and Crop
U	Florida Subtropical Fruit, Truck Crop and Range
V	Hawaii
W	S. Alaska
X	Interior Alaska
Y	Arctic and W. Alaska
Z	Caribbean Area

Major Land Resource Areas (MLRA)
MLRAs and number designation (see Agriculture Handbook 296)

January 1993 1007614

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Crop Residue Management To Reduce Erosion and Improve Soil Quality

Northern Great Plains

W.C. Moldenhauer, Managing Editor
A.L. Black, Regional Editor

Abstract

Moldenhauer, W.C., and A.L. Black, eds. 1994. Crop Residue Management To Reduce Erosion and Improve Soil Quality: Northern Great Plains. U.S. Department of Agriculture, Agricultural Research Service, Conservation Research Report No. 38.

Leaving crop residue on the soil surface during cropping has a number of clear advantages over tillage that leaves the soil surface bare. Most obvious is the greatly reduced erosion from wind and water. This advantage alone makes the change worthwhile. Mandated conservation compliance by 1995 is a further incentive to adopt surface crop residue management. Other advantages include increased yield due to water conserved by surface residue, lower soil temperatures, higher quality soil over time due to increased soil organic matter levels, and, in many cases, reduced input of time, labor, and fuel.

Feasibility of surface residue management has been proven by the increasing rate of acceptance and use by farm operators. Success is due in large part to greater effectiveness and reduced cost of herbicides and the improvement of planting equipment available on the market. Farm operators and conservationists have formed associations and alliances for sharing experiences. Chemical and equipment companies, the farm press, federal, state and local governmental research and extension agencies, along with private organizations, have all published case studies, farmer experiences, and results of research helpful to farm operators.

This is one of six regional publications that assemble research results and experiences for use by farmers and their advisers as they consider the factors involved in changing from tillage to a system of crop residue management.

Keywords: Agricultural economics, conservation tillage, crop rotation, farming methods, erosion, mulch tillage, no-tillage, nutrient cycling, pest management, raindrop erosion, ridge tillage, soil compaction, soil conservation, soil erosion, surface residue tillage, sweep tillage, tillage, water conservation, wind erosion

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While supplies last, single copies of this publication may be obtained at no cost from a local Soil Conservation Service District office.

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone (703) 487–4650.

A copy of the five other regional reports on *Crop Residue Management To Reduce Erosion and Improve Soil Quality* can be obtained from the Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN, 47906 (fax 317–494–5969, telephone 317–494–9555). The other regions are Appalachia and Northeast, North Central, Northwest, Southeast, and Southern Great Plains.

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1 Introduction: Why the Emphasis on Crop Residue Management?

W.C. Moldenhauer and A.L. Black

Soil erosion by wind or water degrades our soils. Besides outrightly removing material from the fertile topsoil, large windstorms or rainstorms selectively remove material high in organic matter and nutrients. The result is surface soil depleted of plant-available nutrients, high in density, and low in porosity and capacity for water intake.

Recognizing the rapidity with which U.S. soils are degrading—especially on the 143 million acres of highly erodible lands—Congress passed the Food Security Act in 1985 to conserve our soils and ensure adequate food supplies for future generations. **The act sets a deadline of December 31, 1994, for full implementation of plans to control erosion on highly erodible lands if farmers are to maintain their eligibility for U.S. Department of Agriculture (USDA) program benefits.** When presented with the broad spectrum of available technologies at USDA-Soil Conservation Service (SCS) offices, fully three-fourths of farmers concluded that the most cost-effective means for controlling erosion on their highly erodible lands was to keep more crop residues on the soil surface.

Any tillage and planting system that leaves all or some portion of the previous crop's residue on the soil surface is described as crop residue management by SCS and the Conservation Technology Information Center (CTIC)) (see chapter 2 for a more complete definition). Three crop residue management classifications described by CTIC are (1) no-till where soil is left undisturbed from harvest to planting except for nutrient injection. Planting is done with least possible disturbance, and weed control is primarily with herbicides; (2) ridge tillage where soil is again left undisturbed from harvest to planting except for nutrient injection. Planting is on the ridges with least possible disturbance. Ridges are rebuilt during a single cultivation; (3) mulch tillage where the soil is tilled, planted, and cultivated with implements and operations that leave the greatest possible amount of surface residue.

Surface residue cover is known to greatly reduce soil erosion. The percentage of the surface needing residue cover depends on the site and other conservation practices included in a total conservation plan. As residue cover approaches 100 percent, soil erosion approaches 0 percent; with 50 percent residue cover, erosion reduction is about 83 percent; when residue cover is 10 percent, erosion reduction is still about 30 percent.

Farmers' willingness to leave residue on the surface was greatly enhanced by the development of herbicides, which provided an alternative to tillage for controlling weeds. Efforts of equipment companies and innovative farmers in developing equipment to leave more residue on the surface and then to plant through it have facilitated the availability and use of crop residue management. The negative effects of crop residue, once looked on as far outweighing the benefits, are now seen as greatly overestimated, or solutions have been found to make the negative results manageable. As the scientific, industrial, and farm communities persistently address the problems and find solutions, they approach remaining problems more as challenges than as insurmountable disadvantages. This change of attitude has played a major role in accelerating the acceptance of crop residue management.

Advances in crop residue management provide flexibility for farmers with highly erodible lands in the Conservation Reserve Program (CRP) who are forced back into production when CRP payments are discontinued. Long-term research shows great advantages in switching directly from sod into no-till management. Besides reducing soil erosion by 80 percent (compared with moldboard plowing of sod), no-tillage retains the benefits to soil structure and organic matter that sod imparts. Chapters 10 and 17 more fully describe the advantages, challenges, and procedures involved in changing from sod to no-tillage.

This publication summarizes research and experience that show the potential benefits and problems related to decreasing tillage and leaving more residues on the soil surface. In the 17 chapters that follow, experts discuss the equipment, management practices, crop protection chemicals, crop rotations, cover crops, and cropping systems that will enable farmers to control erosion on their lands—so they are in Federal conservation compliance—while simultaneously optimizing their net returns and improving the environment and natural resources.

In 1992 a workshop organized by ARS was held in Kansas City to evaluate the state of knowledge regarding crop residue management. The outcomes of that workshop were (1) a volume entitled *Crop Residue Management*, edited by J.L. Hatfield and B.A. Stewart and published in the *Advances of Soil Science* series by Lewis Publishers in 1994, which contained technical information and was available to the workshop participants in 1992, and (2) this series of Regional Reports, which are written in a less technical format and report a broad spectrum of recent findings and observations from scientists, farmers, and SCS and Extension Service personnel.

This northern Great Plains report is one of six regional reports. Some of the technology is suited specifically to the climate and soils of particular regions. However, due to their recent and rapid development, not all of the potentially useful technologies have been tried in all regions. Consequently, some of the surface residue management technologies used in other regions and discussed in the other five reports may apply to the northern Great Plains. A copy of these other reports may be obtained from the Conservation Technology Information Center, West Lafayette, IN (telephone number (317) 494–9555).

Other Sources

Other sources of information on crop residue management include publications of extension and research organizations, chemical and equipment companies, farm magazines, and publications of organizations devoted especially to CRM such as *No-till Farmer*, P.O. Box 624, Brookfield, WI 53008–0624. One recent publication with a great deal of information useful especially in the Midwest region of the United States but also in other regions is MWPS–45, *Conservation Tillage Systems and Management: Crop Residue Management with No-till, Ridge-till, Mulch-till*. This publication is available from Midwest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011–3080.

2 Terminology

David L. Schertz and John Becherer

In the early 1960's the terms *minimum tillage* and *reduced tillage* were used to denote fewer trips over the field. These fewer trips may or may not have left residue on the soil surface after planting or during the critical wind erosion period. The terms did not quantify the amount of surface residue left or any resulting reduction in erosion. The term *conservation tillage* also became popular. This term did imply that some surface residue was left but initially did not specify an amount.

In 1984 the Soil Conservation Service (SCS) defined *conservation tillage* as follows: any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting or at least 1,000 lb/acre of flat small-grain residue equivalent are left on the soil surface during the critical wind-erosion period.

The objective of this conservation tillage was to leave residue on the surface to intercept the eroding forces of rain and wind. This definition remained standard through the early 1990's.

Conservation tillage comprises no-tillage (also called no-till), ridge tillage (ridge till), and mulch tillage (mulch till). They are defined by the Conservation Technology Information Center as follows:

- **No-tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is done in a narrow seedbed or slot made by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is done primarily with herbicides; cultivation may be used for emergency weed control.

- **Ridge tillage.** The soil is left undisturbed from harvest to planting except for during nutrient injection. Planting is done in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is done with herbicides or cultivation or both. Ridges are rebuilt during cultivation.

- **Mulch tillage.** The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is done with herbicides or cultivation or both.

These definitions have gained considerable acceptance. Even so, some confusion remains as to the meaning of conservation tillage. Research shows that surface residue of less than 30 percent may reduce erosion considerably even though, by definition, this amount is not considered conservation tillage.

Most farmers chose to comply with the 1985 Food Security Act to maintain eligibility for USDA program benefits. Many farmers selected practices that left sufficient crop residue on the surface to meet conservation goals. However, some of these tillage practices left less than the amount required. Some people considered conservation tillage to mean only no-till. It became clear that standard terminology was needed to clarify the impacts of leaving all or a portion of the previous crop's residue on the soil surface. The term *crop residue management* evolved to address the benefits of surface residue in reducing soil erosion.

The practice of crop residue management encompasses an entire cropping year. (1) It begins with planting a crop that will provide sufficient residue to achieve a specified goal (that is, controlling erosion to less than 5 tons/acre/yr). Cover crops can be used to supplement low-residue crops. (2) An essential component is good distribution of residue at harvest. (3) It requires carefully planning the depth and speed of any tillage operation to maintain the desired amount of residue on the surface.

Crop residue management is defined as follows:

Any tillage and planting system that uses no-till, ridge tillage, mulch tillage, or another system designed to retain all or a portion of the previous crop's residue on the soil surface. The portion required depends on other conservation practices that may be included in the farmer's total conservation plan.

Throughout this publication, the terms *reduced tillage*, *minimum tillage*, *conservation tillage*, and *crop residue management* are used interchangeably. Each term refers to systems that leave all or a portion of the previous crop's residue on the soil surface to reduce soil erosion to an acceptable level.

3 Description of Region and Subregions

A.L. Black

The northern Great Plains region of the United States includes North Dakota, Montana, South Dakota, Wyoming, Nebraska, and the northeastern portion of Colorado. The western parts of Montana and Wyoming are mountainous, and the western edge of the Great Plains is generally considered to end where elevations exceed 5,000 ft. Topography of most of the cultivated areas of the northern Great Plains is nearly level to rolling.

Climate

Precipitation varies considerably from year to year at any given location in the northern Great Plains. Average annual precipitation ranges from about 10 inches along the western Plains border to more than 20 inches along the eastern border. Snowfall averages 30 inches or more over the region except in southeastern Nebraska and accounts for about 25 percent of the total annual precipitation. About 65 percent of the annual precipitation is received in April through August, and the higher rainfall months of May, June, and July coincide with the high-water-consumption period of small grains. Crops usually suffer at least once during their growth from lack of water, and in the lower rainfall areas crops generally use more water than is received during the growing season. Therefore, in addition to growing-season precipitation, crop growth is highly dependent on stored soil water.

Precipitation decreases progressively from the eastern border of the Great Plains to the western edge. Temperatures and growing-season length both increase from the northern border to the southern border of the region. Average mean temperature from April through September is about 60 °F, and mean annual temperature is about 41 °F. Summer temperatures over 100 °F are not uncommon, and lows of −30 to −50 °F are usually recorded sometime during the winter months.

Winds of high velocity and relatively short duration may occur in any month of the year, but most of the prolonged windy periods occur in March, April, and May. During the spring, winds up to 30-40 mi/hr may occur for several days in succession. Consequently, nearly every year some soil blowing occurs on land that has been sown to winter wheat without adequate crop residue cover and on second-winter fallow land in the spring wheat region. The frost-free growing season ranges from about 90 days in the north to about 150 days in southwestern Nebraska.

Soils

The primary land resource regions discussed in this section are the northern Great Plains spring wheat region (F), the western Great Plains range and irrigated region (G), a portion of the central feed grain and livestock region (M), and a major portion of the upland central Great Plains winter wheat and range region (H). These regions are shown on the large colored map in the pocket inside the back cover of this report.

F. Northern Great Plains Spring Wheat Region
    52. Brown Glaciated Plains
    53. Dark Brown Glaciated Plain
    54. Rolling Soft Shale Plain
    55. Black Glaciated Plain
    56. Red River Valley of the North
G. Western Great Plains Range and Irrigated Region
    58. Northern Rolling High Plains
    59. Northern Smooth High Plains
    60. Pierre Shale Plains and Badlands
    61. Black Hills Footslopes
    62. Black Hills
    63. Rolling Pierre Shale Plains
    64. Mixed Sandy and Silty Tableland
    65. Nebraska Sand Hills
    66. Dakota-Nebraska Eroded Tableland
    67. Central High Plains
H. Central Great Plains Winter Wheat and Range Region
    71. Central Nebraska Loess Hills
    72. Central High Tableland
    75. Central Loess Plains
M. Central Feed Grains and Livestock Region Soils of the Glaciated Plains

Soils of the Glaciated Plains in North Dakota, Montana, and northern South Dakota are medium-textured loam or clay loam soils and have a water-holding capacity of 18-26 percent and organic matter levels of about 2 percent. The texture of the residual soils of central Montana, eastern Wyoming, western North Dakota, and northwestern South Dakota vary from medium coarse to medium to medium fine. These soils have a wide range of water-holding capacity and their organic matter contents are generally less than 2 percent. The sandy soils of the region are residual in origin, and most of the cultivated sandy soils contain less than 1 percent organic matter. The remainder of the loam, silt loam, and clay loam soils in eastern Colorado and central and eastern Nebraska are derived from loess. These soils are deep and well-drained and have water-holding capacities of 22–25 percent in the upper horizons and 18–22 percent in the subsoil loess parent material. Soil organic matter ranges between 1.4 and 1.8 percent over much of this soil resource area. Nearly all the soils in the northern Great Plains are calcareous and have a B-horizon lime layer that varies in depth with soil texture and effective precipitation.

Crops and Crop Rotations

The major crop produced in the northern Great Plains is wheat—totaling 23.9 million acres (16.4 million acres for spring wheat and 7.5 million acres for winter wheat). About

70 percent of this wheat-producing acreage involves use of summer fallow. Few of the other major crops are produced on summer fallow. The second major regional crop is corn—12.1 million acres (10.8 million acres for grain mostly in South Dakota and Nebraska and 1.3 million acres for silage mostly in Montana and North Dakota). There were an additional 9.5 million acres of corn prior to 1985, but this highly erodible land is now part of the Conservation Reserve Program and has been taken out of production and seeded to grass. The remaining major crops grown in descending order of acreage (millions) are alfalfa and alfalfa-grass mixtures for forage (6.9), spring barley (4.9), soybean (4.8), spring oats (2.9), sorghum (2.1), sunflower (1.6), dry beans (0.9), sugar beets (0.4), flax (0.2), and potatoes (0.2).

The principal crop rotation in the western half of the northern Great Plains region is the alternate wheat-fallow cropping system. The winter wheat-fallow systems involve fallowing the land from harvest (July) of one year to seeding (September) of the following year—a 14-mo fallow period and a 10-mo cropping period from seeding (September) to harvest (July). The spring wheat-fallow system has a 3-mo cropping period in one year from seeding (May) to harvest (August) and has a long fallow period from harvest (August) to spring seeding time (in April or May about 21 mo later). Therefore, the period of time that the soil needs crop residue protection from soil erosion during the fallow period is much longer for the spring wheat-fallow system than for the winter wheat-fallow system. Crop rotations in the central and eastern portions of the northern Plains region are continually changing in response to government farm policies. Many of the new rotations include other crops besides wheat and have fallow options every third or fourth year. These rotations include spring or winter cereals, corn, and oilseed crops. Corn is usually grown after soybeans or another crop of corn in the higher rainfall or irrigated areas of the eastern portion of the northern Great Plains. Three-year crop rotations such as winter wheat-corn or wheat-sorghum-ecofallow in western Nebraska, winter wheat-barley-fallow in north central Montana, and spring wheat-oilseed-spring barley or spring oats-fallow in eastern North Dakota are common. The program unique to each farm causes some variation in crop rotation, since the allotted wheat acreage varies and the percentage of nonsurplus crops that can be grown without penalty on designated crop acreage varies.

4 Description of Surface Residue Management Systems in Use

Douglas A. Gasseling, Ronald J. Nadwornick, Charles A. Hogelin, and Roger L. Knable

At the time our forefathers immigrated most of them were not farm operators. They were fishermen, factory workers, craftsmen, or merchants or they were peasant farmers laboring for a land holder; indeed, they came from all walks of life. The first generation had a tremendous change to make in order to survive. The generations that followed prospered by using tillage to gain access to the stored fertility of the virgin prairie land that had accumulated fertility from 10,000 to 15,000 yr of an ecological system of grass, forbs, trees, and animals.

Tillage systems were developed to remove the native cover and replace it with cereals, corn, alfalfa, and other cultivated crops that could use the abundant nutrients. For most of the past it worked very well, except when drought or other misfortunes happened. As droughts periodically occurred, the answer was more tillage. During a droughty year, the land was tilled and left fallow. This procedure was called summer fallow and was based on sacrificing one year's crop to accumulate soil moisture for the next year. The practice became a tradition and still has its defenders.

There are four types of surface residue systems, and they can be categorized by their tilling methods as follows: (1) those that involve mixing as with a disc, cultivator, harrow or rotary tiller; (2) those that involve inverting as with a moldboard plow; (3) those that involve undercutting as with a blade run shallow; and (4) those that involve no tilling or at least drastically reduce tillage operations by using herbicides or rotations or both.

The mixing method has been in use since the first primitive farmers used forked sticks, animal bones, and other objects to scratch the soil. Inverting came into widespread use with the development of the steel moldboard plow and was one of the most effective tillage methods for killing weeds, green manure crops, and sods.

When moldboard plowing is evaluated in terms of residue management, it is one of the most damaging practices that can be used on land. Yet somehow, when this method was being heavily used, our housekeeping instincts perceived that the resulting black and bare soil meant that the soil was being cared for. We went so far as to say the soil was being rested.

Through the years, the introduction of the blade (sweeps) or undercutter has left much more residue on or near the soil surface compared to moldboard plowing. This device was used as a viable tillage method for managing residues in the late forties. Two types of undercutters came into common use from Canadian sources. One was a blade, the other a rod weeder. Both were effective for weed control and keeping residue on the surface.

The surface residue systems used in the northern Plains region vary from state to state and within each state. The major factors that have impeded the adoption of surface residue systems have been fears of residue-borne disease, inadequate weed control, lower yields, and the cost of equipment changes.

The northern Plains producers are gradually moving to systems that are leaving more residue on the soil surface year-round. The major residue systems used are the traditional tilling system leaving from 1 to 15 percent residue; a reduced-till system leaving 15 to 30 percent residue; and mulch-till, ridge-till (strip till), and no-till systems having greater than 30 percent cover. The traditional system (moldboard plowing) has been considered by many as conventional farming. Over the years, however, the systems leaving more residue have gradually become more common.

As equipment for sowing seed and placing fertilizer in higher amounts of surface residue has improved, the portion of the residue left on the surface has increased. The use of systems that conserve surface residues continues to grow, especially in the northern area of the northern Plains. Tables 1 and 2 can be compared to changes that have been documented by the Conservation Technology Information Center (CTIC) at West Lafayette, IN.

The definitions of tillage systems used for the survey results in tables 1 and 2 are as follows:

1. No-till: Preparation of the seedbed and planting is completed in one operation. Soil disturbance at planting time is limited to the area contacted by the rolling coulter. A minimum of 90 percent of the previous crop residue is left on the soil surface immediately after planting.

2. Ridge till: Preparation of the seedbed and planting is completed on ridges. Ridges are usually 4–8 inches higher in elevation than the row middles. Ridges are maintained and rebuilt through prior year cultivation. A minimum of 65 percent of the previous crop residue is left on the soil surface immediately after planting.

3. Strip till (unridged): Preparation of the seedbed and planting are completed in one operation, and tillage is limited to a narrow band centered on the row. The area between rows, exclusive of tillage bands, is undisturbed. A minimum of 50 percent of the previous crop residue is left on the soil surface immediately after planting.

4. Mulch till: Preparation of the seedbed involves loosening and/or mixing the soil and incorporating a portion of the

previous crop residue into the soil. Tillage tools include chisels, wide sweeps, discs, harrows, and others. A minimum of 33 percent of the previous crop residue is left on the soil surface immediately after planting.

5. Reduced Till: Conventional tillage strips are reduced as a result of vegetative chemical control, combined tillage operations, or multifunction tillage tools. A minimum of 20 percent of the previous crop residue is left on the soil surface after planting.

The definitions used for the National Survey of Conservation Tillage Practices underwent a significant change in 1989. After 1988 strip-till and reduced-till systems were no longer surveyed. Three of the systems surveyed before 1989—no-till, ridge till, and mulch till—continued to be surveyed after 1988. These three categories are defined in chapter 2 and they absorbed the strip-till and the reduced-till that were deleted for 1988. Two new categories were established systems leaving 0–15 percent residue and 15–30 percent residue. These definitions were used in the 1992 survey shown in table 2. The 15–30 percent residue systems are defined as those in which 15–30 percent residue cover is left after planting or 500–1,000 lbs of small-grain residue equivalent during the critical wind erosion period. The less than 15 percent residue systems are defined as those in which less than 15 percent residue cover is left after planting or less than 500 lbs of small-grain residue equivalent during the critical wind erosion period.

The amount of land under systems that conserve surface residue should continue to increase as the January 1, 1995, deadline for implementation of the 1985 Farm Bill (Food Security Act) and the 1990 Food and Agriculture Conservation Trade Act approaches. The amount of acres with residues on the surface should also continue to increase as the equipment technology improves.

Table 1. Survey results from the 1982 National Survey of Conservation Tillage Practices

System	Number of Acres				
	Montana	Nebraska	N. Dakota	S. Dakota	Wyoming
Reduced till	1,405,000	4,086,151	1,000,000	1,814,000	12,000
Mulch till	0	1,362,051	0	1,344,000	1,000
Ridge till	0	415,452	1,000	16,500	0
Strip till	0	506,082	0	80,000	0
No till	150,800	568,002	87,700	30,000	0

Source: National Survey of Conservation Tillage Practices Including Other Tillage Types, CTIC, West Lafayette, IN.

Table 2. Survey results from the 1992 National Survey of Conservation Tillage Practices

System	Number of Acres				
	Montana	Nebraska	N. Dakota	S. Dakota	Wyoming
0–15%	2,113,618	3,074,783	7,513,783	4,632,942	425,703
15–30%	3,010,532	4,786,388	6,431,819	4,265,198	209,933
Mulch till	1,802,224	4,650,137	4,332,863	3,097,001	107,722
Ridge till	928	1,337,735	45,061	168,358	1,500
No till	390,567	1,582,210	664,945	985,700	7,295

Source: National Survey of Conservation Tillage Practices Including Other Tillage Types, CTIC, West Lafayette, IN.

5 Interactions of Surface Residues with Soil and Climate

G.A. Peterson

Surface residues have major, positive benefits in Great Plain's agriculture, the foremost of which are improved water conservation and decreased soil erosion potential. Degree of benefit is dependent on the particular soil and the climate prevailing in that area. Surface residues also may have effects on agroecosystems that are detrimental to plant growth and require management adjustments to ameliorate. For example, early spring soil temperature may be reduced by residue cover, and this can reduce yields of spring-planted crops in northern latitudes.

This chapter addresses interactions of surface residue accumulation with soil and climate factors. These interactions determine whether the residue effects are positive, neutral, or even negative. Issues to be discussed are (1) problems with cold soil temperatures, excessively wet soil conditions, and high-runoff situations; (2) interactions affecting crop rotation choices and cover crops; and (3) the use of surface residue management in conjunction with other conservation measures.

Problems Related to Cold Soils and Excessive Soil Water

McCalla and Duley (1946) showed that corn residue mulches decreased soil temperatures in midsummer (July-August) at Lincoln, NE, by 6–13 °F as mulch rate varied from 2 to 8 tons/acre. They were attempting to lower summer temperatures to decrease evaporation of water. This exemplifies an ameliorative effect of residue on a negative process, summer evaporation. Al-Darby and Lowery (1987) showed that soil cover of 55–87 percent in no-till conditions lowered soil temperatures by as much as 7 °F compared to the temperature of conventionally tilled soils during spring in Wisconsin. Full corn seedling emergence was delayed by 2–8 days when seeds were planted in no-till systems instead of in conventionally tilled systems. Although emergence was delayed and plant growth slowed during the early parts of the season, final corn grain yields were not significantly different for any system tested under these environmental conditions. The authors concluded that the additional water savings in the no-till system compensated for the early season delays in plant growth. Producers must be prepared to deal with delayed growth of spring crops in mulch-till and no-till systems because of low soil temperatures. For example, delayed crop emergence may allow weeds to grow rapidly without competition. These larger weeds would use more water and nitrogen and other nutrients and would generally decrease crop yield. Therefore, proper attention to weed control, planting dates, cultivar selection, and starter fertilizer are vital when one knows cold stress will occur. In general the need for intense management increases whenever additional stresses are imposed.

Soil properties that affect water infiltration, permeability, and drainage must always be properly assessed when making residue management decisions. Factors that cause soils to remain wetter longer generally cause them to be colder. Again this is only a problem with spring-planted crops, but in the northern Plains the problem applies to spring wheat, other spring cereals, corn, and grain sorghum. The latter two species, corn and grain sorghum, are particularly sensitive compared to the small grains. Research in the Corn Belt has shown that no-till management on some poorly drained soils has resulted in lower yields compared to the yields for conventional tillage. Continued research has shown, however, that continued use of no-till and disease-resistant cultivars has overcome the negative response and yields after 18 yrs of no-till and that yields from no-till are now equal or greater than yields from conventionally tilled fields. Therefore, producers with poorly drained soils should expect lower productivity in the initial years after switching to high-residue systems. It may be best to avoid complete no-till in these situations. Ridging and bedding may help reduce adverse effects of high-residue systems on poorly drained soils, and may in fact be better long-term choices than strict no-till practices. Grain yield responses to no-till on well-drained soil have increased with time under surface residue systems (Dick et al. 1991). For a more comprehensive discussion of long-term effects of tillage systems see chapter 18 of this publication.

A general summary of expected responses to no-till and reduced till is given in table 3. Soil texture, slope, and drainage classification are the key factors in choosing a tillage system. Poorly drained soils are not easily adapted to high-residue systems and may be better managed with limited till systems than with strict no-till. Coarse-textured soils, even when poorly drained, are less of a problem than fine-textured soils in the same drainage category. Well-drained soils are good candidates for no-till and reduced till (ridge and mulch till) if they are silt loam or coarser in texture. Silty clay loam and silty clay soils may present problems for planting equipment if they are wet and therefore would be best managed with a more highly disturbed system—perhaps ridge till. All steeply sloping soils regardless of textural class are best managed with reduced-till or no-till systems because their runoff and erosion potentials are high.

Weed Control Problems Related to Soil, Climate, and Tillage Choice

In the northern Plains, weed control problems tend to increase in initial years when farmers convert to systems that leave most of the residue on the soil surface. With less burial of weed seeds, greater weed emergence seems to be the norm. Grassy weeds like downy brome (*Bromus tectorum*) are particularly favored when tillage is reduced.

Furthermore, substitution of sweep tillage for mixing and inverting operations (disks and plows) makes grassy weed control more difficult. Weeds that have growth cycles that synchronize with the crop cycle are the major offenders in these cases. Downy brome, for example, germinates in the fall when soil temperatures begin to fall below 60°F—about the same time as winter wheat planting. This type of weed is especially difficult to handle in monoculture systems like continuous winter wheat or winter wheat-fallow.

Crop rotation is one of the best ways to combat weed problems in any system, and this is especially true in reduced-till and no-till situations. By changing crop type, one can control weeds at a different point in their growth cycle. For example, following wheat, a cool-season plant, with crops like sunflower, millet, and corn (warm-season plants) gives an opportunity to control weeds that are a problem for wheat.

In high-residue systems herbicides substitute for part or all of the weed control provided by tillage in conventional-tillage systems. Close adherence to the labels of these herbicides is essential for maximum weed control benefits to be achieved. Required rates of application can vary with soil texture and organic matter content. In general the finer textured soils and those with higher organic matter content require higher rates of soil-applied herbicides in order to get weed control. Clays and organic matter inactivate these herbicides, and therefore rates must be adjusted as described by the manufacturer. Caution also must be exercised in conjunction with herbicide carryover to the next crop. Soils that are coarse textured, low in organic matter, and high in pH are particularly susceptible to carryover problems.

Conversion to high-residue systems dictates that growers have or acquire herbicide management skills. Correct sprayer operation (from calibration to nozzle type selection) is the key to success in residue management systems. New technology is being developed that will allow selective application of a herbicide over a landscape and will greatly aid in judicious use of herbicide materials. For a more comprehensive discussion of weed control, consult chapter 13 of this publication.

Crop Rotations and Cover Crops in Relation to Agroecosystems

Traditional wheat-fallow farming has been a mainstay in the northern and central Great Plains since before 1940. It has been used in both the spring and winter wheat areas for the purpose of stabilizing grain production and thereby minimizing risk for the farmer and the surrounding community. Much research has been focused on improving the efficiency of water storage during the fallow period. Each additional unit of water stored has resulted in improved grain yields. Greb (1979) summarized progress in the central Plains in terms of water storage efficiency, water use efficiency, and grain yield. Decreased stirring during fallow markedly increases water storage and subsequent yield potential. Decreased tillage also maintains more residue cover on the soil surface. When conventional tillage is used, water storage efficiencies are only 19–27 percent. The use of minimum till and herbicides increases water storage efficiencies to about 40 percent. Grain yields more than double in some cases as water storage improves.

Climate gradients exist in the Great Plains that often require management strategies to be altered with geographic location. However, the usefulness of residue mulch to improve water storage potential has proven to be universal despite the fact that evaporative demand increases from north to south in the Great Plains. Greb (1979) summarized the effect of straw mulch on fallow water storage from four locations ranging from Bushland, TX, to Akron, CO, to Sidney, MT, and found that 2,000 lb/acre of straw mulch increased water storage efficiency by 24 percent compared to the efficiency of no cover. A straw mulch applied at 4,000 lb/acre improved storage efficiency by 42 percent. Effectiveness of the mulch was not related to geographic location. Variability from site to site was greater than the effect of climatic gradient. For fall-planted crops, soil temperature issues are not a factor, and therefore the impacts of straw mulch are all positive throughout the Plains. In the case of spring-planted crops, the wetter soils and lower temperatures associated with the mulch can be detrimental. Willis and Power (1975), for example, reported that at Mandan, ND, 6,000 lb/acre of mulch reduced the daily maximum temperature at planting depth in May to 68 °F as compared to 85 °F with no mulch. Soil temperature differences during the night were very small.

Because additional water is conserved when residues are maintained on the surface, more intensive management cropping systems are possible than with the traditional system of wheat-fallow. Smika and Wicks (1968) reported that no-till systems with good weed control conserved 6 more inches of water than plowed systems after 11 mo of fallow (July–May) at North Platte, NE. This moisture conservation allowed production of a grain sorghum crop without intervening fallow. They were able to use a wheat-sorghum-fallow rotation as a result of surface residue maintenance. McGee (1992) reported that storage efficiency from July (wheat harvest) to May of the next year (corn planting) averaged 58 percent at two northern Colorado locations over a 2-yr period for three different soils at each site. The extra moisture permitted production of corn crops with average corn grain yields of 75 bushels/acre on all soils at both sites, which is excellent for that area.

Throughout the Plains, corn is being produced in both wheat-corn-fallow and wheat-corn-millet-fallow rotations. Changing from wheat-fallow to these more intense cropping systems has increased surface residue accumulation at the wheat planting point in the rotation from 2,100 lb/acre for the wheat-fallow rotation, to 3,400 lb/acre for the wheat-corn-fallow rotation, to 3,900 lb/acre for the wheat-corn-millet-fallow rotation. These major increases in residue accumulation under the more intense cropping systems increased cover and enhanced water conservation, providing a positive feedback to the overall system.

Cover crops have not been used in the northern Plains area to any great degree because they use water that is being saved for the next primary crop. Winter leaching is not a factor in most years in the area, so there is no need to provide a nitrate sink via a cover crop. However, recent work in this area suggests that lentils or field peas can be used as green manures in spring wheat-fallow systems when grown for about 8 wk in spring of the fallow year.

Surface Residues and Other Conservation Measures

Maximizing snow catch is a vital conservation measure in the northern Plains. Since snow constitutes 20–25 percent of the annual precipitation, it represents a valuable resource for agriculture in these drylands. Stubble height management is a tool used to maximize snow catch. Taller stubble retains more snow but also can increase spring melt runoff in the northernmost parts of the Plains. Wet fallow soils, which freeze deeply prior to snowfall and remain frozen and nonconductive to water while under snow cover, provide the worst scenario for meltwater runoff. However, on soils in which annual crops are grown, infiltration of snowmelt occurs 80–90 percent of the time because the soil is usually frozen dry enough to permit infiltration. In the central Plains area, snowmelt is more easily captured because soils do not freeze as deeply and often thaw under the snow and because substantial snowfall occurs after spring thawing begins. Greb (1979) reports that the efficiency of storing meltwater is often double that of storing water received as rain.

Summary

Maintaining residues on the soil surface is a valuable management practice in all parts of the northern Great Plains in terms of enhanced water capture and retention. However, the cost of storing the additional water with improved residue management can decrease profit if producers do make changes to use the water. Intensification of cropping systems is one of the best means of obtaining an economic benefit from the additional stored water.

Finally, producers should be aware that residues may have negative effects in terms of colder soil temperatures during spring planting. Appropriate system choices including planting method, crop choice, starter fertilizer decisions, etc., can help ameliorate the potentially negative cold temperature effects.

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Table 3. Tillage system recommendations as related to soil textural class, drainage, and slope

Drainage and Slope	Tillage system recommended*					
	Sand	**Fine Sandy Loam**	**Loam**	**Silt Loam**	**Silty Clay Loam**	**Silty Clay**
Poorly drained	NT or MT	NT or MT	R or B	R or B	R or B	R or B
Well drained, slopes less than 7%	NT or R	NT or R	NT or R	NT or R	NT or R	NT or R
Excessively drained, slopes greater than 7%	NT	NT	NT	NT	NT	NT

**B*, Bedding; *MT*, minimum till; *NT*, no-till; *R*, ridge till.

6 Managing Seed Zone Soil Water

A.L. Black

Crop residue and vegetation cover are the key factors that affect both soil and water conservation. Since available water (soil water plus growing season rainfall) and its efficient use are primary factors controlling crop yield potential, the economic sustainability of northern Great Plains agriculture can be improved through the application of improved water conservation and crop use technology. Researchers have shown that each additional inch of available water used, beyond the approximate 4 inches required to reach the initial yield point, produces an average of 5.1 bushels/acre of spring wheat or 6.8 bushels/acre of spring barley. Therefore, water conservation technology can be discussed in terms of immediate economic benefits (bushels of grain per inch of water conserved)—unlike soil conservation technology, which has a long-term economic consequence that is often not perceived by producers as affecting crop yields.

The focal point of water conservation is crop residue (stubble) management. Residues simultaneously reduce water evaporation rate and retain precipitation (snow and rain). Effective water conservation should be realized where residues are retained on the soil surface. Advances in minimum-, mulch-, and no-till equipment technology have provided additional opportunities to maintain high levels of surface residues for conserving soil water and managing seed zone soil moisture. Good water management is necessary for optimizing the growth of crops in minimum-, mulch-, or no-till crop production systems.

Water Conservation During Noncrop Periods

The wheat-fallow cropping system involving either winter or spring wheat is the primary cropping system in the northern Great Plains. The sections that follow discuss specific seasonal segments of the noncrop periods that apply to both annual cropping and crop-fallow systems.

Period Between Harvest and Soil Freezeup

The precipitation received in July, August, September, or October (following harvest of various winter or spring crops) is important for production of the next crop and must be conserved. The opportunity to conserve water in the soil profile before soil freezeup diminishes when long-season crops like, corn, sorghum, soybeans, sunflower, or safflower are grown instead of winter wheat or spring cereal grains. For instance crops like spring barley or early seeded spring wheat in the northern portion or millet and winter wheat in the southern portion of the northern Great Plains region are usually harvested in July. This early harvest widens the time interval between harvest and fall soil freezeup and increases the opportunity to conserve precipitation received during that time. Conversely, full-season crops use water well into the fall, thereby limiting the time between harvest and soil freezeup in which precipitation can replenish soil water supplies.

Aside from choosing a crop, there are two other management decisions that affect potential water storage before winter. These decisions must be made at the time of harvest or following harvest, particularly if cereal grain crops were grown. First, the cutting height of the swathing or combine platform must be adjusted for the stubble height that is most effective for snow trapping. (Stubble height in relation to overwinter soil water storage will be discussed in the next section of this chapter.) For minimum- and no-till crop production systems, it is critically important that the combine be equipped to adequately spread straw and chaff over the entire width of the header. Second, the choice of how to control weeds and volunteer grain must be made and the decision implemented. The average amount of soil water that could be lost to weeds and volunteer grain after a winter wheat crop ranges from about 3.0 inches in the southern portion of the region to about 1.5 inches in the northern portion of the region.

Saving soil water after harvest is important anytime, but it becomes especially important when the winter snowfall is low or in those years when overwinter soil water gains are relatively low. Weed control in the fall should be accomplished without destroying the upright position of the stubble of the previous crop so as not to destroy the snow-trapping potential. Some wide V-blade or flat-sweep-type implements can be used to undercut the stubble and control weeds and volunteer grain and still leave the stubble in a relatively upright position to trap snow. Herbicides can also be used for the control of volunteer grain and weeds and also leave the stubble standing in a more upright stance.

Period Between Late Fall and Spring (Overwintering Period)

Numerous researchers in the northern Great Plains have documented the soil water conservation aspects of standing stubble compared to fall tillage systems that flatten or bury the residue. During 45 location-year studies, the average soil water gain during overwintering was 1.5 inches greater for fields having upright stubble (10–17 inches tall) than for fields in which stubble was flattened or incorporated during tillage.

Investigations of stubble height management for optimal snow trapping, water conservation, and crop yields indicate that intermediate stubble heights of 10–12 inches provide higher no-till crop yields than taller (15–18 inch) or shorter (4–6 inch) stubble heights. Winter wheat seeded into standing stubble (barley, spring wheat, or flax stubble) of this height is protected from winterkill soil temperatures at crown depth and is therefore maintained at an optimum population level. Soil temperatures in standing stubble fields are 6–8 °F warmer in late-fall months than those in conventional till soils. Fields with standing stubble trap snow and therefore do not freeze as deeply in the soil profile as bare fields.

Period Between Spring and Fall (Summer-Fallow Period)

The evaporative demands brought about by warmer temperatures during the summer of the fallow period are very high, so the actual quantity of water stored during this period is usually low. In the northern Great Plains regions where winter and spring wheat are grown, 60–84 percent of the total soil water stored during a 14- or 21-mo fallow period is stored during the fall and winter after harvest. Research has shown that the summer fallow period is a very inefficient water-storage period in which moisture may actually be lost during the hot July–August period.

Three criteria must be met before soil water can be stored during the summer fallow period. First, the soil in the root zone must not already be at or near the water storage capacity after the first overwinter period. If this soil is at capacity, summer fallowing will allow deep percolation of water below the root zone, and this deep percolation can contribute to saline seep development and possibly to groundwater degradation. Second, precipitation for storms must occur in sufficient quantity to cause soil water to move deep enough into the soil (4–5 inches). Deeper penetration reduces the fraction of the water subsequently lost by evaporation. Third, the quantity of crop residue available to suppress evaporation rates must be relatively high.

With regard to the first criteria, if the available soil water supply in the root zone is at or near capacity, the field should be cropped rather than fallowed. Summer fallow should be used only when soil water levels in the soil profile are so low that there is significant risk of crop failure. The planting schedule, therefore, should remain flexible. Whenever there is sufficient water in the soil at planting time to provide good probability of a satisfactory net income from a crop, that crop should be planted.

For surface crop residues to be effective in storing precipitation in the soil during the summer fallow period, rainfall must be received in sufficient quantity and frequency to allow deep percolation. Research shows that wheat stubble on the soil surface reduced the first-stage evaporation rate in the short term but that total evaporation losses from the soil profile in the long term, when no more water was added, were about the same after 20 days for bare soils as for mulched soils with less than 2,000 lb/acre of residue. If significant rainfall occurs frequently enough, say every 10 days or fewer, then the reduced first-stage evaporation rate due to surface mulching can be beneficial and a net gain in stored soil water will result. The lesson to be leaned from these studies is that while thin and incomplete mulches generally reduce initial evaporation rates, they do not always significantly reduce the total amount lost to evaporation.

Assuming the stubble was kept upright enough to trap snow during overwintering in the spring, the producer should make an estimate of the quantity of residue present at the beginning of summer fallow. If residue production from the previous crop provides less than 2,500 lb/acre (60 percent cover) at the beginning of the summer fallowing, a producer should consider using only a chemical fallow program to conserve soil and water resources. If residue levels are in the range of 2,500–4,000 lb/acre, a combination of minimum tillage (sweeps, 16-inch or wider) and herbicide sprayings should be used. When crop residue levels are greater than 4,000 lb/acre, various combinations of disk, chisel, twisted-shank, and duck-foot-type tillage implements can be used sparingly to reduce crop residue levels sufficiently so that they are not a problem during seeding operations of the next crop.

Period of Second Overwintering (for Spring Wheat-Fallow Only)

In the spring grain-fallow cropping system, the second winter period of fallow is of major concern from the standpoint of maintaining sufficient residue cover to protect the soil from wind erosion. Minimum- and no-till fallow methods have the potential to reduce relative wind erodibility to about one-tenth of that which occurs in conventional bare-soil tillage systems.

The amount of precipitation stored during the second winter of fallow averages only about 10 percent of the total quantity stored during the 21-month fallow period. Soil water storage during this period can range from a loss of 0.8 inches to a gain of 1.2 inches. These results are readily understood if one considers that the soil profile at the start of this period is usually near its maximum storage capacity in the upper 2 ft. The fact that the soil is near capacity causes most of the additional precipitation to evaporate or percolate below the root zone. In addition, soils freeze during this period and virtually prevent infiltration of snowmelt or rain while the soil is frozen. This is not true for the soil in the first overwintering period when standing stubble fields are usually dry in the upper 2-ft profile and snowmelt or rainfall can infiltrate frozen soils that are dry at the beginning of the period.

Management of Soil Moisture in the Seed Zone

Surface crop residue management is the key to soil water conservation and management of soil moisture in the seed zone for improved crop yields. Tillage deeper than 3 inches causes excessive drying and soil water loss (as much as 0.5 inch) and often results in poor stands of fall- or spring-seeded crops. Soil moisture in the seed zone and the resulting seedling population can be controlled by the producer, and they constitute two of the most important factors contributing to optimum crop yields.

Soil moisture must be within reach of the depth to which the seeding equipment can place the seed. Proper position and orientation of crop residue combined with no-till or shallow (2 inch) sweep tillage usually helps maintain adequate moisture levels in the seed zone. If the producer maintains residue cover at 50 percent or higher, soil moisture usually will be present at about the 2-inch depth, which is within the reach of most seeding equipment. If residue cover levels are less than 50 percent, wide (16-inch or more) undercutter sweeps or a rodweeder should be operated at a shallow depth (2 inches) 3–4 wk prior to fall or spring seeding to preserve soil moisture in the seed zone.

Residue, Water, and Temperature Interactions

In the spring, residue cover on the soil surface insulates the cold soil from the warming air and heat generated from more intensive and prolonged sunlight. This tends to slow the rate of soil warming and can delay emergence of crops sown in the spring on no-till fields compared to crops sown on conventionally tilled fields.

However, when wheat is sown in the fall into standing wheat or barley stubble the surface residues tend to keep the soil warmer and promote more growth. Standing stubble also traps more snow during the cold winter months, often protecting the crop from winter kill temperatures and enhancing soil water supplies. These benefits derived from fall seeding into crop residues accompanied by increased infiltration and decreased evaporation are resulting in better yields and consequent movement of fall-seeded wheat into the traditional spring wheat areas of the United States and Canada.

When soil moisture contents are high during the time of spring grain planting, soil temperatures are usually cooler in residue-covered soils than in bare soils. Tilling the soil exposes moist soil, resulting in evaporative cooling and a marked decrease in soil temperature during the first day or so. The darker, less insulated surface absorbs more heat and warms up after the surface has dried. However, 2 or 3 days and considerable moisture are generally lost in the process of this tillage, and seed must generally be placed 3 or 4 inches deep to reach moisture in the tilled soil. Experienced producers are patient and wait for the upper soil surface (0–1.5 inches) to start drying before seeding into surface residue management systems without tillage. This wait is usually only 2–4 days. Because soil moisture is close to the surface in no-till fields, seed placement can be shallower, that is, 1.5–2.0 inches instead of 3–4 inches. Soil temperatures are relatively warm at the shallow depth and can facilitate quick germination and rapid plant emergence.

With row crops like corn or sunflower, soil temperature and soil water conditions at planting can be beneficially modified in conservation tillage systems by using strip till or ridge till. (See the report *Crop Residue Management To Reduce Erosion and Improve Soil Quality: North Central Region* for guidelines and for additional information on row crops.)

7 Economics of Residue Management

Richard T. Clark, James B. Johnson, and Jennifer Brundson

Soil erosion causes on-site damage to crops and off-site damage to resource amenities enjoyed by society. On-site damages directly affect crop producers, but many of these impacts are gradual and go unrecognized by producers. Off-site damages primarily impact society in the aggregate and far exceed on-site costs to producers. For that reason society has taken legislative action to reduce wind and water erosion.

Improved residue management is generally a cost-effective means of erosion control in the northern Great Plains. Many conservation plans developed by the Soil Conservation Service in cooperation with agricultural producers to meet compliance requirements involve improved residue management.

This chapter includes a brief discussion of off-site and on-site impacts of erosion. Much of the chapter discusses an evaluation procedure for on-site benefits or costs that may result from changing to a higher residue cropping/tillage system.

Off-Site Effects of Erosion

Nonpoint pollution is responsible for at least half of all U.S. water pollution. Agricultural production can result in off-site sedimentation, chemical contamination, saline loading, and other pollution problems. Society, not the individual agricultural producer, usually bears the cost of these problems. Estimates of off-site costs of nonpoint pollution are often expressed as a range and an approximate (or "most likely") point estimate. These estimates are crude, but they do provide a starting point for evaluating off-site economic impacts of agricultural nonpoint pollution. The Conservation Foundation has provided estimates of these off-site impacts.

Total annual in-stream and off-stream damages attributable to erosion in the United States were estimated at $6.1 billion with a range of $3.2 to $13 billion. About 36 percent of these damages occurred on cropland. Damages to recreation areas accounted for most of the major in-stream effects of erosion. Average damages have been estimated at about $2 billion with individual estimates ranging from $1 to $5.6 billion. About 42 percent of these recreational area damage costs are attributable to erosion from cropland. In-stream damages also occurred to water storage facilities and water transportation. Major off-stream costs were from flood damages and harm to water transportation and water treatment facilities. These estimates were in 1980 dollars.

Most estimated off-site erosion costs are based on the impacts of erosion on water quality. Wind erosion often reduces air quality and fills road ditches and fence rows, but broad scale estimates of the cash value of damages due to wind erosion are not available.

On-Site Effects of Erosion

Technological improvements have masked on-site costs of soil erosion. Improved varieties, fertilizers, and other agricultural chemicals have increased yield, and these technologically induced yield increases have often exceeded yield losses due to erosion. Erosion of topsoil affects different soils in different ways. Soil nutrient loss is a primary effect in the northern Great Plains. In addition the subsoil may react differently than the topsoil to applied fertilizers, thus reducing yield response. Erosion also degrades soil structure, resulting in increased surface sealing to water and soil crusting. These effects may reduce seedling emergence and water infiltration. Timing of operations and energy requirements may also be affected as the soil erodes.

Erosion can reduce yields by placing eroded soil on plant seedlings. This effect can happen with both wind and water erosion. Blowing soil can abrade and kill young seedlings. If the damage is severe, yield losses may occur or the farmer may be forced to reseed the field.

All of the negative effects can result in reduced crop yields, increased costs, or both. Recent studies, however, point out that the overall crop yield loss from erosion in the northern Great Plains is not large. One major modeling study projected a 1.4-percent yield loss over the next 100 yr based on erosion rates and cropping practices followed in 1982. The magnitude of this projected yield loss was small, partly because the modeled fertilizer inputs were permitted to increase. Certain soils may be impacted more dramatically and have larger productivity losses because of soil loss.

A recent Agricultural Research Service study in the northern Plains has shown that 1 ton/acre additions of organic matter in the upper 12 inches of soil increased the yield of spring wheat one-half bu/acre. If erosion removes 10 tons/acre of soil per year containing 4 percent organic matter, then spring wheat yields could drop by 0.2 bushels/acre/yr or 10.0 bushels/acre over a 50-yr period. The present value of such a decline discounted over 50 yr at a discount value as low as 5 percent is just under $11/acre for wheat valued at $3/bushel.

Reductions in net farm income due to productivity decreases attributable to soil erosion may have only minor impacts on the producer's short-run profitability. However, these short-run impacts may adversely impact the future value of the land resource and therefore the producer's financial net worth. These long-lasting financial and economic considerations may encourage producers to use residue management and other conservation practices to control erosion. Long-term effects of tillage and residue management are discussed in more detail in chapter 18 of this report.

On-Site Incentives for Residue Management

Voluntary Incentives

In the northern Great Plains, proper residue management often preserves soil moisture. Moisture preservation is observable and may give producers economic incentives for adopting residue-preserving systems. Although the main focus on residue management may be for erosion control, the primary economic stimulus for voluntary adoption comes from moisture preservation and sometimes reduction in purchased inputs. Enhanced producer profitability is usually the central focus of the evaluation criteria for substituting any new tillage method for one already in use.

Conservation tillage, which emphasizes residue management, has received considerable acceptance in the more-humid, higher rainfall production regions of the northern Great Plains where continuous cropping is predominant. Often, introduction of conservation tillage results in the elimination of a tillage operation. For instance, the ridge-plant method increases residue on the field surface and eliminates one or more tillage operations. The method is also useful for controlling weeds and thus minimizing herbicide requirements. Ridge planting is becoming more prevalent in irrigated areas such as southwest and central Nebraska. Nebraska Extension budgets for irrigated corn estimate that the total costs per bushel are essentially the same for corn produced from ridge plant and conventional systems.

Leaving more residue on the surface is also becoming more prevalent in the more arid reaches of the Great Plains. The ecofallow system has been adopted by many producers in central and western Nebraska, northern Kansas, and south central South Dakota. This tillage method uses a combination of chemicals and tillage to control weeds. In areas of the northern Great Plains where average annual precipitation is between 16 and 18 inches, the ecofallow system is used in a 3-yr rotation of winter wheat-corn (or sorghum)-fallow. Because more moisture is conserved by increased amounts of residue on the surface, two crops are produced in 3 yr with this ecofallow system instead of one in two with traditional wheat-fallow systems.

In addition the individual crop yields from the ecofallow system tend to be better than the yields from the traditional tillage and fallow operations. Long-term research by the University of Nebraska at North Platte shows that ecofallow winter wheat out yielded winter wheat in the same rotation with full tillage (no mold board plow) by about 5 bushels/acre (40 versus 35 bushels/acre). Sorghum yields were as much as 15 bushels/acre higher (50 versus 35 bushels/acre) for the ecofallow system compared to the yield from the full tillage operation. The full-tillage system included a pass by a disc plus sweep tillage. Ecofallow usually did not involve any tillage prior to planting, but one treatment included shallow tillage prior to planting wheat.

Kansas State researchers found that reduced-till winter wheat in a wheat-fallow rotation out yielded conventionally tilled winter wheat by an average of 7 bushels/acre (38 versus 31 bushels/acre) over 11 yr. Winter wheat in the reduced-till, 3-yr rotation system (winter wheat-sorghum-fallow) out yielded winter wheat in the same rotation but conventionally tilled by over 6 bushels/acre (37 versus 30 or more bushels/acre). Sorghum in the reduced-tillage, 3-yr rotation out yielded conventionally tilled sorghum in the same rotation by nearly 13 bushels/acre (53 versus 40 bushels/acre) over the 11-yr study. Total costs for the reduced-till systems exceeded those for conventional systems by 6–7 percent, yet profitability of the reduced-till systems was much higher. In addition income variability was less with the reduced-till operations. Although the Nebraska and Kansas studies indicate greater net returns for systems that reduce tillage and leave more residue on the surface, this result is not universal throughout the northern Great Plains.

Some studies in relatively arid areas (such as Montana) of the northern Great Plains report that those systems with increased crop residue cover increased costs and reduced net returns. For instance, net returns produced from minimum-till (combination of two tillage passes plus herbicides) and no-till (herbicides only) methods under a flexible cropping system in northeast Montana were $24.51 and $21.10 per composite acre, respectively. A composite acre was defined as an acre used 50 percent of the time for crop growth and 50 percent of the time for fallow. However, decreases in the prices of productive inputs, such as herbicides, could effectively change the economic competitiveness of these residue management tillage methods. Small per-acre changes in net returns of $3.41 for each composite acre can have substantial aggregate impacts for producers who farm an average of 3,000 acres of cropland, that is, net returns annually will change $10,230.

In central North Dakota, researchers found that a change in crop rotation was needed to obtain full economic advantage from the additional water-conserving aspects of high-residue management systems. In one study the average net annual return for a 2-yr spring wheat-fallow rotation was about $21 per cropland acre regardless of whether conventional till, minimum till, or no-till systems were used. In the same study, a spring wheat-winter wheat-sunflower rotation produced an average annual net return of about $32 for conventional till, $42 for minimum tillage, and about $43 for no-till per cropland acre, respectively. Changing crop rotation accounts for about half of the potential advantage ($11) and the remaining increase was because the tillage change increased the return for the new rotation over conventional till.

Statutory Incentives

The conservation compliance provision of Title XII, "Conservation," of the Food Security Act of 1985 made eligibility for most U.S. Department of Agriculture benefits contingent on developing and implementing a conservation plan to limit soil erosion on highly erodible land. Those provisions were strengthened in the conservation section of the 1990 Food, Agriculture, Conservation and Trade Act.

Although conservation compliance is voluntary for the agricultural producer, it is economically essential for most agricultural producers in the northern Great Plains. These producers depend on the income offered by deficiency payments for program commodities such as wheat, corn, and barley. In 1991 about 92 percent of the wheat base, 87 percent of the corn base, and 82 percent of the barley base in the northern Great Plains states were enrolled in commodity programs and were eligible for deficiency payments. Many also depend on other USDA programs such as Federal Crop Insurance to protect income positions during periods of catastrophic crop loss.

Conservation plans were developed by agricultural producers in cooperation with the Soil Conservation Service for highly erodible croplands that were in production prior to December 23, 1985. The applicable conservation plans are designed to achieve substantial reductions in soil erosion. These conservation plans were designed to be technically and economically feasible.

Many northern Great Plains conservation plans identify improved residue management as the major erosion control practice. In Nebraska about 80 percent of the compliance plans feature improved residue management. In Montana nearly all compliance plans feature residue management as a major practice.

The decision of whether or not to use a high-residue management system rests with the farmer. Each farm's soil, climate, and other resources are unique, and producers need to evaluate on-site economic incentives to see whether improved residue management is cost effective for erosion control on their farm. The section that follows offers some general guidance for making an economic evaluation of residue management.

Evaluating Residue Management on an Individual Farm

Changing to operations that leave more residue on the surface does not usually require dramatic changes in the farming operation especially if no cropping changes are required. Consequently, a partial budget analysis is often adequate for examining on-site economic issues. Even in cases where the high-residue system requires changes in crops, partial budgeting can be used. A partial budgeting analysis evaluates only those costs and returns that change. The idea is to compare the new system (high-surface-residue farming) to the old (conventional tillage). For example, if harvesting costs are not likely to be significantly affected, harvesting cost can be deleted from the comparison.

Equipment and Ownership Costs

Higher surface residue systems usually require changes in tillage and planting or drilling equipment. Equipment designed to effectively deal with higher residues often is more expensive than equipment used in conventional systems. For example, a six-row ridge planter could have a purchase price of about 10–60 percent more than a comparable planter not designed for ridges. A cultivator designed specifically for ridge systems may have a purchase price that is nearly 50 percent more than the purchase price of a conventional cultivator. Existing equipment can often be modified to adapt to residue management. These modification devices can be obtained from dealers.

Many high-residue systems substitute herbicides for tillage operations. Producers without adequate herbicide application equipment may need to purchase new equipment or modify existing equipment.

Whether or not a producer should attribute all of the ownership costs of specialized equipment to the higher residue system depends on the situation. A producer whose drill needs replacing anyway should not attribute all of the annual ownership costs of a new high-residue drill to the higher residue management system. Appropriate ownership costs would be depreciation, taxes (if applicable), insurance, and a real opportunity cost of capital (real interest rate) on the difference in the purchase prices of the residue drill and the conventional drill, that is, if the higher residue drill is more expensive. This example assumes that the producer will get rid of the old equipment when the new equipment is obtained. However, there is a tendency for producers in the western portion of the Great Plains to keep their conventional equipment when they acquire the necessary high residue equipment. The producer then has two sets of equipment, and this may result in higher total ownership costs than before. Two sets of equipment are likely to occur on farms that have both highly erodible and relatively nonerodible land. The producer will be farming fewer acres with the conventional equipment, so each acre will need to offset more of the equipment ownership costs. Increased acreage through leasing or purchasing of additional acreage has allowed some farmers to more fully utilize their equipment and reduce equipment cost per acre.

Operating Costs

Some operating cost differences will occur when switching from conventional tillage to an improved residue management system. Depending on the system, these costs could go up or down. Systems that are either no-till or that approach no-till will have reduced fuel, lube, and repair costs compared to conventional-till systems because fewer (if any) tillage operations are needed. Some systems such as a ridge plant system may not change operating costs very much, since ridge planting usually requires more expensive equipment that may have higher repair costs and fuel costs. The higher fuel costs are generally a result of increased horsepower and increased time of operation.

Most systems that maintain high residues on the surface substitute herbicides for tillage to control weeds. As a consequence, chemical costs are usually expected to be greater for high-residue systems in traditional wheat-fallow systems. The cost differences between the use of pesticides for the high-residue and conventional-till systems should be estimated and included in a partial budget assessment. The operating costs associated with the pesticide application should also be included. If more diverse annual crop rotations are adopted to use the additional water conserved with high-residue systems, herbicide costs of the high-residue systems may be similar to those encountered in conventional-till systems.

Fertilizer costs could change if the change in residue systems is expected to change fertilizer losses, application methods, crop yields, the crop mix, or the cropping intensity. For example, higher corn yields may require additional nitrogen, since nitrogen recommendations are in part a function of expected yield. Changing the crop mix and cropping intensity could also alter fertilizer needs.

Labor Costs

Differences in labor requirements should also be estimated before making the decision to switch from conventional till to a residue management system. Some reduced-till systems may require less labor because fewer passes over the field are required. In other comparisons labor cost could change very little. For instance, ridge plant systems usually require more time per operation but involve fewer operations. Therefore, the net changes in labor cost for this system must be assessed carefully.

Labor should be assessed on its worth on the basis of its opportunity cost. The opportunity cost is the value of the labor if used to do the next most valuable thing it could do. If there is nothing else for the operator or a full time hired worker to do when the labor is saved, the opportunity cost is at or near zero. However, if adopting reduced-tillage methods permits the operator to reduce the number of employees or do some other productive task, there will be a savings. For example, labor savings from adoption of no-till has permitted some producers to farm additional land without adding labor-intensive equipment. In such cases the opportunity costs of the saved labor would be high. Availability of adjacent land and opportunities for off-farm work, public service, or recreation, all become major factors in a farmer's decision of which management system is best.

Effects on Gross Return

Gross return is output times the price received. In the case of program crops, such as corn and wheat, that are produced under the Acreage Reduction Program operated by the Agricultural Stabilization and Conservation Service (ASCS), gross returns may include deficiency payments.

If switching from conventional till to a high-residue system changes yield, then a change in gross returns should be expected in the partial budget analysis. If the residue system changes the mix or cropping intensity of crops produced, then gross returns should reflect the different crops and appropriate prices.

Changes in returns (and costs also) can be calculated on a per-acre or whole-farm basis. If calculated on a per-acre basis, the returns from rotations must be based on a composite acre that reflects the rotation. Even on a whole-farm basis, the analysis must reflect the rotation. In the case of a 50–50 wheat-fallow cropping system, for example, one-half of the acres would be evaluated as if planted to wheat and one-half would be treated as fallow.

The returns for cropland in the acreage reduction program are more difficult to estimate. Again, care must be exercised so that the comparison between systems is not incorrectly influenced by how the deficiency payments are calculated and applied. Under current law (1993–1995), the residue management program cannot affect the ASCS payment yield known officially as the historic weighted yield (HWY). That yield has, for all practical purposes, been frozen since 1985. Producers who begin producing a "new" program crop because of their residue management program must have a crop acreage base for that crop to be eligible for deficiency payments. For example, suppose a producer had traditionally been under a wheat-fallow system. By farming with higher levels of residue, that producer can now go to the wheat-corn-fallow system. Without any corn base, it would be inappropriate to credit the system with expected corn deficiency payments. Producers should consult their local ASCS representative relative to crop acreage bases and ASCS yield concerns.

Format for Partial Budget Analysis

A partial budget analysis involves the following four steps:
Step 1. Identify changes to be made.
Step 2. List assumptions and key information such as expected changes in yield, cropping mix, equipment, prices, etc.

Step 3. Estimate the effect of the change on net returns.
Step 4. List other considerations and factors that may be difficult to evaluate in terms of dollars.

This four-step analysis does not address possible cash-flow problems that may be encountered. The partial budgeting analysis assesses the economic viability of the change, assuming it is successfully implemented. If a profitable change requires a major cash outlay to acquire a no-till planter, the producer may need to complete a cash-flow analysis. The cash-flow analysis would show whether or not principal and interest payments on the new planter could be made. Cash-flow analysis can also be used to assess the cash impacts of "learning" the system. Perhaps crop yields, for example, would decline for 2 yr while the producer learns how to farm with the new system—a 2-yr projected cash-flow could factor in that possibility. In summary a partial budget analysis that indicates a profitable change from an economic perspective does not necessarily mean that cash-flow will improve.

The example below assesses the profitability of a contemplated change in tillage method and is used to illustrate the four steps involved in the partial budget analysis technique.

Illustration of Partial Budget Analysis

Step 1. Change being considered:
The conservation plan for a producer in an area receiving an average of 15 inches of precipitation per year in the northern Great Plains calls for a switch from a winter wheat stubble mulch-fallow rotation to winter wheat-chemical/tillage fallow. No change in crop acreage is planned.

Step 2. List of pertinent information:

a. Because research at a nearby university ag research center shows that chemical/tillage fallow conserves more moisture, yield is expected to increase by 5 bushels/acre.
b. No change in the fertilization program is expected.
c. Tillage operations will be reduced by eliminating two passes with a large sweep (undercutter) and one pass with a rod weeder.
d. One custom spraying operation with herbicides will be added.
e. No change in equipment will be necessary.
f. No change in farm program payments will occur.
g. Wheat is valued at $3.11/bushel (10-yr average).
h. Labor savings amount to .2 hr/acre/yr. Opportunity value of the labor savings is $0.0, since there aren't enough labor savings to eliminate any full-time employees and there is little else for them to do that time of year.
i. Management is expected to be more difficult.

Step 3. The effect of the change on net returns:
If the estimations made are accurate, then the producer should be able to increase net returns by making the switch to the new rotation. The estimated increase in net returns is shown by the following:

		dollars/acre*
A.	Change in returns from production	+$15.55
B.	Change in deficiency payments if participating in farm program	$0.00
C.	Net change in gross returns (A plus B)	+$15.55
D.	Change in operating costs, including hired labor	+$4.13
E.	Change in net returns above operating costs (C minus D)	+$11.42
F.	Change in annual ownership costs	$0.00
G.	CHANGE IN NET RETURNS TO OPERATOR (E minus F)	+$11.42

*Assign (+) for increase and (−) for decrease.

The improved yield assumption made in step 2 was critical. Per-acre costs actually increased but were offset by the revenue increase from the yield increase of 5 bushels of wheat. The producer should recognize that the improved yield potential may not be realized every year. However, the producer may calculate the break-even yield requirement by dividing the net increase in costs of $4.13 (D plus F) by the price of the product (wheat at $3.11/ bushel) to establish a break-even yield increase of 1.33 bushels/acre. Yield equal to or greater than this break-even yield should generally be achieved if the producer is experienced with the type of change proposed. Other more complex changes may be assessed with this procedure. The analyst must be careful to include all variables that actually change.

Step 4. Other considerations:
The new rotation system will reduce wind erosion, meet the conservation compliance plan, and conserve soil moisture to help in dry years. However, it will require more management, including planning and study time.

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8 Fertilizer Management

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Adoption of conservation tillage systems by farmers in the Great Plains will present new challenges. Profitable crop management will require careful attention to details and a positive interaction between farm inputs (fertilizers) and management practices. The Manitoba-North Dakota Zero Tillage Farmers Association indicates that zero tillage (no-till farming) is an economical, viable alternative to conventional-tillage methods. No-till reduces soil erosion and at the same time increases the potential for using more intensive cropping systems than the traditional crop-fallow system.

A viable farm economy depends on setting yield goals with production inputs based on cost per unit of production. The overall strategy should be to develop fertilizer management strategies and yield goals that result in the most efficient use of available resources and that maximize net economic returns. Fertilizer management strategies geared for high yields and efficient production are often more effective in maintaining productivity and reducing environmental problems caused by erosion and chemical contamination than average- or low-input management systems. Tillage methods, fertility management, and other activities related to crop production influence soil formation and soil erosion—processes that are continuous and naturally occurring. High-yielding crops produce healthy, vigorous root systems that more thoroughly explore the soil profile (root zone), thus making more efficient use of the available water and nutrients. Long-term effects of tillage and their interactions with soil fertility are discussed in more detail in chapter 18.

Yield goals should be based on past experience (such as a 5-yr average of yields), on expected level of plant-available water (soil water plus expected growing season precipitation), and on other yield-limiting factors. The risk associated with selected yield goals should be carefully considered. Profit is the compensation a farmer gets for considering and minimizing his risks. Resources, such as soil, climate, and finances, will help determine the acceptable level of risk. Environmental goals also need to be set and should be based on the management practices adopted. Farmers can reduce the risk of damage to the environment and still use management practices that produce optimum yields at low unit costs. To accomplish this, the farmer must base farm practices on a systematic approach to tillage, fertility, and overall crop management.

Fertilizer requirements for growing crops under no-till and reduced-tillage systems are generally the same as for those under conventional tillage. In no-till systems, there is a perceived need to get the nutrients through the accumulated residues and into the underlying soil to attain their most efficient use. Water, nitrogen (N), and phosphorus (P) are generally the most limiting nutrients for crop production in the northern Great Plains. Potassium (K) and sulfur (S) levels are generally adequate in most soils for most crops.

Over a period of time, reduced- and no-till systems will increase the level of plant nutrients accumulating near the soil surface. This stands to reason, since crop residues accumulate at the surface in reduced-tillage systems, and subsequent residue decomposition and mineralization will occur near the soil surface. In conventional-till systems crop residues and nutrients are mixed more thoroughly in the tillage zone.

Soil Testing

Soil testing and plant analysis are effective tools for a good fertility program. A soil testing plan should be developed on each farm to provide information on each field at least every 2–3 yr for P and K. Soil testing for residual nitrate-N availability should occur at the beginning of each growing season. Accurate records on soil test results and sample location should be maintained to allow subsequent tests to be taken from the same area so that changes in nutrient status can be assessed with time.

Many soils in the Great Plains are low in available P. Fertilizer applications should be based on soil test results, previous crop yields, and yield goals established for each field. The North Dakota and South Dakota Extension Services are using this approach for estimating fertilizer applications (tables 4 and 5). When P is at moderate levels, the timing and method of application are less critical and more fertilizer options will exist.

Although soil tests are generally accurate, different interpretations of soil test results may result in variations in fertilizer recommendations. Therefore, consideration needs to be given to local interpretations and recommendations. When making fertilizer recommendations, one needs to assess factors that will affect yield potential, such as weed level, planting date, variety, soil water, expected growing season precipitation, residual soil nitrate-N level, and P fertility level, before estimating N needs.

Soil Sampling

Soil test values are only as representative of the field as the samples are. For soil test results to be meaningful, samples must be taken from the proper depth. Surface (tillage layer or 0–6 inch depth) samples are used for determining soil pH and content of soil organic matter, P, K, and micronutrients. The same sampling depth should be used from year to year so that soil test values can be compared over time to assess the cumulative effects of fertilizer application and crop removal. Both surface and subsurface samples are needed to estimate nitrate-N, sulfur, and chloride in the root zone.

Most soil testing laboratories recommend that at least the top 2 ft of soil be sampled for nitrate-N, S, and chloride. Deeper samples to 4 ft would improve the accuracy of N fertilizer recommendations and provide information on the environmental impact or potential for nitrate-N leaching due to past N fertilization practices used. With deep soil test information, N fertilizer recommendations can be adjusted according to residual nitrate-N in the root zone.

Before soil samples are collected, fields should be divided into uniform areas based on soil type, slope, degree of erosion, cropping history, known crop growth differences, and any other factors that may influence nutrient levels in the soil. Odd areas in the field, such as eroded spots, turnrows, abandoned farmsteads, or feedlots, should be sampled separately. Soil samples can be collected at random in the sample area or in a grid pattern. Random collection may be faster; however, more samples will need to be collected from the entire area to obtain the most reliable results. Grid sampling takes longer but helps ensure that the entire area is represented in the sample.

Collection of one composite sample for each 20 acres is generally recommended though one for each 40 acres is acceptable in uniform fields. Surface samples should each contain a mixture of 15–20 soil cores. Surface samples contain a mixture from 6–8 cores. Late fall or winter is a good time to sample the soil, except for when samples for nitrate-N are being taken on sandy soils. Sampling just prior to planting is ideal if the analysis can be completed in time to order and apply the fertilizer and plant. For additional details on soil sampling procedures, consult the guidelines developed by the local State Experiment Station or Cooperative Extension Service.

Nitrogen Management

Plant available N is present in the soil in the ammonium (NH_4) and nitrate (NO_3) forms. NO_3 is very mobile and moves readily as water moves in the soil. Thus, as plants take up water, NO_3–N will move toward the plant roots. Likewise, NO_3–N can be leached below the root zone during times when plants are not growing. NH_4–N is less subject to leaching. However, NH_4–N is converted rather rapidly to nitrate through nitrification when soil temperatures are above 50 °F. Nitrification can be slowed by use of nitrification inhibitors. Nitrogen losses by volatilization of ammonia or by conversion to N oxides in denitrification can be a problem in some soils. Biological immobilization of surface or subsurface N applications may occur in the presence of large amounts of crop residue, reducing the availability of N to plants.

Managing N for high yields while protecting the environment and groundwater will require soil testing to assess the residual N in the crop root zone. Assessing the residual N in the entire root zone improves the accuracy of N fertilizer recommendations and assesses any potential adverse impacts of past fertilizer management practices on groundwater quality. A nitrogen budget based on total crop N needs, yield potential, and residual soil NO_3–N is a good way to evaluate N fertilizer needs.

The guidelines provided in table 4 for estimating fertilizer needs in North Dakota and South Dakota take into account yield goal, residual soil N, date of soil sampling, and previous crop. The sampling date adjustment (SDA) is used to account for the amount of nitrogen that will be mineralized from recently incorporated residues between the time of sampling and the time when the next crop begins to grow. In the northern Plains this rate of biological mineralization of nitrogen from recently incorporated crop residues averages about 0.5 lb/acre/day from the time of harvest till about September 15, when soils cool rapidly and mineralization decreases abruptly to practically negligible values. Mineral N measured in soil samples at that time is considered to be available for use when the crop begins to grow. Mineral N measured in samples taken earlier in the summer will generally be less by about 0.5 lb/acre/day. For instance, if a sample taken on August 16 were left in the field till September 15 (30 days), it would contain about 15 lb/acre more mineral N. Consequently, the amount of fertilizer N needed to fill the needs of the next crop is estimated to be less than the soil test nitrogen (STN) by the SDA, which is 15 lb/acre for samples taken on August 15.

Recent studies reported in chapter 18 indicate that the rate of residue decomposition is highly dependent on the type of tillage and is particularly low for no-till. Consequently, the SDA is probably smaller than this average in no-till systems.

A similar approach to N management is used in Montana and Nebraska. For more detail on fertilizer recommendations in Montana and Nebraska, consult the Cooperative Extension Service fertilizer guides from these states.

Phosphorus

When P fertilizer is added to soil most of it is converted to chemical forms that are less available than the fertilizer form. P movement in soil is minimal. P reaches plant roots primarily by diffusion, which is a slow process. Consequently, application of P close to where root development occurs will result in most efficient plant use. Placement becomes particularly important when cold soil temperatures retard root development and nutrient uptake. Placement is also important when dry weather reduces available soil moisture, since the diffusion rate of P fertilizer to plant roots is reduced when soil moisture is low. Regardless of tillage system used, maintaining a high soil test level of P provides the most flexibility in selection of tillage and fertilizer placement options.

If P soil test levels are low and application rates are low (<20 lb P_2O_5/acre), placing the P fertilizer with or near the seed is the most effective means of application in conservation tillage systems. As soil test levels increase from medium to high, method of P placement becomes less of a concern. In the northern Great Plains, a single high rate of application of broadcast incorporated P has been shown to be effective for 17 yr. Implementing this type of P management strategy requires examination of P management goals, length of land tenure, financial status, P fertilizer costs, and short-term economics. If possible, it is desirable to build the soil test P level to the critical level (approximately 16–25 ppm) and then maintain that soil test level with smaller maintenance applications during each planting. This strategy allows the crop to optimize yield potential and economic returns in both dry and wet years.

There are two basic P management strategies. One strategy is to build soil P to a critical level, and then maintain that level of soil P by applying each year only the amount of P removed by the previous crop. The other strategy is to apply enough P to last for several years and test the soil occasionally to determine when P levels are getting down to the level where applying additional P will increase net returns.

Potassium

Movement of K in the soil is slightly greater than that of P but much less than that of nitrate-N. K is held on the negatively charged clay and organic matter particles in the soil. Low soil temperatures and moisture stress can contribute to K deficiency in crops. Soil tests for K are good indicators of the soil's K supply for most crops. Many of the finer textured soils in the northern Great Plains are high in plant-available K. However, on sandy soils responses to K fertilization may occur during a cold spring. The most common type of K fertilizer is KCl (potassium chloride, 0–0–62). Soils deficient in chloride may also benefit from the chloride additions in KCl.

Sulfur

Sulfur (S) levels in the soils of the northern Great Plains are generally high. Reports of S deficiencies for any of the major crops are rare. S soil tests have not been very reliable for predicting S needs of crops. A knowledge of S deficiency symptoms of crops will aid in identifying an S nutrient problem. Removal of most of the S from coal-fired power plant flue emissions in response to the Clean Air Act will substantially reduce the amount of S received on cropland via the rain. In the future, S deficiencies will therefore become more common.

Other Nutrients

Calcium and magnesium are generally not yield-limiting factors for crops in the northern Great Plains. Micronutrients also are generally not a problem for the major crops in the northern Great Plains. However, zinc (Zn) can be deficient in corn growing on soils with high levels of calcium carbonate or P. Sandy soils are frequently low in Zn, resulting in Zn deficiency in corn. Zn deficiency in wheat, however, is very uncommon. High levels of P can induce a Zn deficiency in wheat, corn, and other crops.

Chloride (Cl) has been reported to be deficient under some soil and climatic conditions in wheat and barley in the northern Great Plains. Positive yield responses to Cl have been reported in Montana, North Dakota, and South Dakota. The major benefit of Cl fertilization has been in disease suppression in wheat and barley. A soil test for Cl has been developed.

Iron deficiency may occur in sorghum and less frequently in corn on some soils. Other micronutrients such as manganese, copper, molybdenum, and boron are seldom deficient for plant growth; however, concentrations of these elements in forage or grain may be low enough to require supplemental additions for adequate livestock nutrition.

Fertilizer Facts

Fertilizer grade is expressed in terms of the percentage of N, P_2O_5, and K_2O in the fertilizer mixture. For example, a 10–12–17 fertilizer contains the equivalent of 10 percent N, 12 percent P_2O_5, 17 percent K_2O. The *Western Fertilizer Handbook* (see California Fertilizer Association (1985) listed in "Other Sources" at the end of this chapter) provides more detailed information on fertilizers, fertilizer grades, and other chemical information. The following is a guide for making conversions in nutrient analysis of fertilizers:

$P_2O_5 \times 0.436 = P$ or $P \times 2.29 = P_2O_5$
$K_2O \times 0.83 = K$ or $K \times 1.21 = K_2O$
$NO_3 \times 0.226 = N$ and $NH_3 \times 0.822 = N$

Fertilizer Placement

Soil texture, crop grown, tillage system, climate, and soil test level are among the factors that dictate which fertilizer placement method would work best for a given situation. When soil test levels are high, placement method makes little difference. However, when soil test levels are low, particularly for P, band placement of some sort will usually show the most immediate yield advantage during the year of application.

Soil characteristics are important in making decisions relative to fertilizer placement and timing. Sandy soils often require more frequent nutrient applications because of low cation exchange capacity and potential for leaching of plant nutrients below the root zone. On sandy soils, N should be applied as close as possible to the time of greatest plant uptake for most efficient use. A split N application may be more efficient than a one-time application. Silt loam soils generally have relatively high water holding capacity, good nutrient storage, and a high level of productivity. Clays and clay loam soils have the highest level of nutrient and water holding capacity but are often subject to physical limitations such as compaction.

Alkaline soils (those with a pH above 7.0) require a special P management strategy. Placement of P in a band near the seed and in combination with ammonium-based fertilizers will help improve P.

Broadcasting provides for a uniform distribution of fertilizer nutrients throughout the soil profile and therefore in the root zone and can also be used to apply some herbicides. N fertilizers are usually incorporated after broadcasting to reduce possible volatilization losses of ammonia from high-N fertilizers such as urea. P and K may be left on the surface for extended periods as long as the potential for runoff is minimal. Generally, all nutrients will be more efficiently used if they are incorporated after broadcast application. This presents some problems for broadcast applications in no-till systems where incorporation by tillage is not desirable.

Positional unavailability of surface-applied nutrients may be a problem in low-rainfall periods. Broadcasting of N in no-till systems often results in lower N-use efficiency because of positional unavailability, immobilization, or volatilization losses of ammonia. Fluid N fertilizers are particularly susceptible to not being used efficiently when broadcast because they are in intimate contact with surface crop residues.

Variable rate applications of fertilizer are coming into the picture as technologies are developed. Since most fields do not have a uniform fertilizer need because of soil and crop variability, application of variable fertilizer rates throughout a field to match field variability will result in more efficient nutrient use and more protection of the environment.

Band applications of fertilizers can provide an advantage over broadcasting when it is beneficial to concentrate the fertilizer into a narrow band near the seed to provide a higher concentration of nutrients. Banding is especially useful where soil test levels are low, where early season root growth is limited by cool or wet conditions, or where surface crop residues limit the contact of fertilizer with the soil. Banding of P at low fertilizer rates on soil low in P or on soils that have a high tendency to fix P in unavailable forms generally results in more efficient uptake of the P by the crop.

There are several types of banding applications. Generally, all types of banding application for N, P, K, and micronutrients result in more of the applied fertilizer material being used during the first cropping season. *Surface strip banding* involves the application of solid or fluid fertilizers in bands or strips of varying widths on the soil surface or on the surface of crop residues. *Deep banding* refers to preplant applications of nutrients injected 2–6 inches below the soil surface. *High pressure injection* uses the cutting action of high-pressure streams to place liquid fertilizers below the crop residue and below the soil surface. *Point injection* uses a spoke wheel applicator to place fluids below the surface with little disturbance of surface crop residues. This process can be done preplant or postplant. *Starter or seed-placed banding* places applications of nutrients close to the seed at planting time, which is particularly useful for getting crops off to an early start in cool, wet soils.

Seedling damage from banding N can occur unless the fertilizer is placed far enough from the seed. To avoid damage: (1) place anhydrous ammonia 2–3 inches away from the seed, (2) place urea based N products 1–2 inches from the seed, and (3) place ammonium nitrate or liquid N 0.5–1 inch from the seed. As soil texture changes from a loamy sand to a clay, the amount of N as urea that can be safely placed directly with wheat seed increases from about 12 lb N/acre to about 30 lb N/acre. Local recommendations should be checked before applying more than 10–12 lb N/acre directly with the seed.

Equipment now available allows a producer to use most any type of fertilizer application method. Drills are available that can band high rates of N between seed rows and apply lower rates of P fertilizer with the seed. The technology and equipment for one-pass operations to seed and fertilize at the same time is now available for use in high-residue management systems.

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Table 4. Equations for estimating crop N and K_2O fertilizer application rates as a function of yield goal and soil test level in North Dakota and South Dakota

Crop	Yield unit	Equation for estimating application rate of:* N (lb/acre)	K_2O (lb/acre)
Wheat	bu/acre	2.5YG−STN+SDA−PCC	(2.71−0.017STK)YG
Malting barley	bu/acre	1.5YG−STN+SDA−PCC	(1.29−0.0085STK)YG
Feed barley	bu/acre	1.7YG−STN+SDA−PCC	(1.29−0.0085STK)YG
Oat	bu/acre	1.3YG−STN+SDA−PCC	(1.28−0.0086STK)YG
Millet	lb/acre	0.035YG−STN+SDA−PCC	(0.03−0.00018STK)YG
Sunflower	lb/acre	0.05YG−STN+SDA−PCC	(0.041−0.00027STK)YG
Safflower	lb/acre	0.05YG−STN+SDA−PCC	(0.048−0.0003STK)YG
Flax	bu/acre	3YG−STN+SDA−PCC	(2.20−0.014STK)YG
Mustard, rapeseed, or canola	cwt/acre	6.5YG−STN+SDA−PCC	(5.40−0.034STK)YG
Crambe	lb/acre	0.05YG−STN+SDA−PCC	(0.054−0.00036STK)YG
Grain corn	bu/acre	1.2YG−STN+SDA−PCC	(1.17−0.0073STK)YG
Silage corn	tons/acre	10.4YG−STN+SDA−PCC	(9.50−0.06STK)YG
Grain sorghum	bu/acre	1.1YG−STN+SDA−PCC	(0.88−0.0058STK)YG
Edible beans	lb/acre	(YG−1400)(0.088−STN +SDA−PCC)	(0.035−0.00021STK)YG
Grass, range	tons/acre	25YG	80−0.53STK

**YG*, yield goal; *STN*, soil test N (lb/acre); *STK*, soil test K (ppm); *SDA*, sampling date adjustment; *PCC*, previous crop credit.

Source: Dahnke and Fanning (1992).

Table 5. Equations for estimating crop P_2O_5 fertilizer application rates as a function of yield goal and soil test level in North Dakota and South Dakota

Crop	Yield unit	Equation for P_2O_5 application rate:*	
		Using Olson soil test	Using Bray-1 soil test
Wheat	bu/acre	(1.07−0.067STP)YG	(1.07−0.054STP)YG
Malting barley	bu/acre	(0.79−0.05STP)YG	(0.79−0.039STP)YG
Feed barley	bu/acre	(0.79−0.05STP)YG	(0.79−0.039STP)YG
Oat	bu/acre	(0.64−0.041STP)YG	(0.64−0.032STP)YG
Millet	lb/acre	(0.017−0.0011STP)YG	(0.017−0.0009STP)YG
Sunflower	lb/acre	(0.023−0.0014STP)YG	(0.023−0.0011STP)YG
Safflower	lb/acre	(0.027−0.0017STP)YG	(0.027−0.0014STP)YG
Flax	bu/acre	(1.17−0.073STP)YG	(1.17−0.058STP)YG
Mustard, rapeseed, or canola	cwt/acre	(3.60−0.22STP)YG	(3.60−0.17STP)YG
Crambe	lb/acre	(0.036−0.0023STP)YG	(0.036−0.0018STP)YG
Grain corn	bu/acre	(0.70−0.044STP)YG	(0.70−0.035STP)YG
Silage corn	tons/acre	(5.62−0.35STP)YG	(5.62−0.28STP)YG
Grain sorghum	bu/acre	(0.67−0.041STP)YG	(0.67−0.033STP)YG
Edible beans	lb/acre	(0.023−0.0014STP)YG	(0.023−0.0011STP)YG
Grass, range	tons/acre	45.0−3.45 STP	45.0−2.5 STP

*_YG_, yield goal; _STP_, soil test P (ppm).

Source: Dahnke and Fanning (1992).

9 Crop Residue Effects on Water Quality

John Gilley

Surface residue on cropland areas may significantly affect both surface and groundwater quality. Contaminants may be transported by either surface runoff or through subsurface water flow. Surface runoff may carry chemical constituents, either dissolved or attached on sediment. Before chemical constituents can move downward through the soil profile, they must first be dissolved.

Crop Residue Effects on Runoff and Groundwater

Runoff from cropland sites may serve as a transport mechanism for chemical constituents. Residue, in turn, influences the quantity and rate of water movement over the soil surface. Thus, surface water quality can be improved by proper residue management.

Crop residues intercept and adsorb some rainfall. The percentage of rainfall retained by crop residues is large when the amount of rainfall is small. For those storms that produce significant amounts of rainfall, the fraction of total rainfall retained by crop residue is usually small.

On tilled surfaces soil seals generally develop from the impact of raindrops physically breaking down soil clods and aggregates. The formation of a surface seal may substantially limit water infiltration. The presence of crop residue on the surface can greatly reduce the development of surface seal by dissipating the impact energy of raindrops. Crop residues lying on the surface tend to restrain and pond runoff water during high-intensity storms. Large pores open to the surface then become conduits for rapid water movement from these ponds into the soil, substantially increasing infiltration.

The ponding and retention of water caused by crop residue can obstruct and divert runoff and therefore diminish runoff velocity. A reduction in runoff velocity increases the time water remains on the site and causes greater infiltration. Surface residue may also prevent small localized flow channels from combining into larger networks that could form rills. A well-established rill network allows runoff and suspended sediment to be rapidly transported from an area.

Relatively small amounts (500 lb/acre) of crop residue have been found to substantially affect total runoff volume. A smaller runoff volume translates into a reduced potential for off site surface water quality problems. Reduced volumes of runoff in areas with crop residue are the result of greater infiltration rates and times.

Water stored within the soil profile may be used to support the crop. If water in excess of the storage capacity is introduced into the soil profile, it will move downward beyond the root zone and will recharge the underlying aquifer. Often the water reaching the aquifer may contain some nitrate. Avoiding excess water application is often possible under irrigated conditions by adjusting water supply to the consumptive-use requirements of the crop.

In most of the Great Plains, lack of precipitation is the most common and serious factor limiting crop production. A large portion of this area is left fallow to increase the amount of soil water available for the next crop. The potential for water movement below the root zone is greater under a crop-fallow system than under a system in which crops are grown every year.

On some dryland farming areas in the Great Plains, precipitation in excess of the storage capacity of the soil-root zone may cause elevated water tables and saline seeps. This supply to the water table is most likely to occur during fallow periods. As water passes through the soil profile toward the water table, soluble salts and nitrate may move downward and may result in groundwater quality concerns. Intensive, flexible cropping systems that adjust crop water use to inherently variable precipitation and reduce or eliminate the need for summer fallow have been used to successfully control saline seeps. Crop residues on the soil surface can increase infiltration, decrease evaporation, and provide more efficient storage of soil water. Adoption of improved agronomic practices, including crop residue management, can make continuous cropping possible and thus reduce water quality concerns associated with saline seeps.

In the northern Great Plains on areas that are cropped continuously, the water capacity of the soil in the root zone is seldom reached and therefore the hydraulic conductivity of the soil generally remains low. Consequently, the migration of water through the soil profile and into groundwater is usually a relatively slow process that may take several years in the eastern Plains and decades or centuries in the drier western Plains. Use of a crop rotation may reduce flow into groundwater. Crops such as alfalfa, sorghum, and sunflowers have relatively deep roots and, if used in a rotation, can overtake and absorb soil water and nitrate that has percolated beyond the reach of shallower rooted crops.

Precipitation in the Great Plains during the growing season usually supplies less water than is required for a crop's consumptive use. Consequently, on nonirrigated areas, soil water stored within the root zone is usually depleted by the end of the growing season and the soil is ready to absorb several inches of water during the cold season when there is little use of water by plants. Recharge of groundwater is limited and contamination of groundwater is usually not a problem on continuously cropped, nonirrigated sites in the Great Plains.

In contrast, the potential for substantial movement of water and nitrates to the ground water exists on irrigated areas. Fertilizers, herbicides, and pesticides are used extensively on irrigated sites. If water in excess of the crop's consumptive use requirements is applied, soil water and dissolved contaminants may move into the groundwater.

Crop Residue Effects on Sediment Delivery

Many agricultural chemicals readily attach to soil particles. If soil particles having chemicals attached to them are removed from a cropland site through erosion, they affect surface water quality. Surface residues influence runoff volume, quality of the runoff, amount of sediment eroded from an area, and amount of sediment that is capable of causing offsite damage.

Impacting raindrops are the primary detachment mechanism for interrill erosion. Crop residues and the small ponds that they cause during a downpour serve to dissipate raindrop energy. Besides reducing runoff and the degree of surface sealing, crop residues also minimize raindrop-induced soil detachment and therefore decrease the amount of interrill sediment transport.

Concentrated flow (in contrast to sheet flow) serves as the primary detachment mechanism for rill erosion. Crop residues reduce soil detachment in rills by holding the soil in place. Residues also increase the roughness of the flow channel area and cause the velocity of the flowing surface water to decrease. As residue cover increases in rills, the ability of the flow to detach soil particles is reduced.

Sediment being transported in runoff is eventually deposited somewhere. Deposition of sediment is a selective process, with the largest or most-dense particles being deposited first. Strip cropping and stiff grass hedges crossing the direction of water flow reduce sediment delivery from cropland areas. Crops capable of restraining different amounts of residues can be planted in alternate strips. Strips containing the crop that restrains more residue will normally tend to disperse concentrated flows and reduce the transport capacity of the runoff enough to cause significant sediment deposition either within the strip or upstream from the residue strip or grass hedge where runoff water commonly ponds.

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10 Transition from Clean Till to Surface Residue Systems

Dwayne Beck

Whether or Not to Park the Plow

Each producer's situation is unique. Only the producer can decide whether to make operational changes or not and when and how such changes should be made. Making the transition from a farming system based on intensive tillage to one where substantial amounts of residue are left on the soil surface is like most major changes: it involves substantially more thought than simply trying to decide whether to park the plow or trade it off. This chapter will outline some of the most important factors that need to be considered before and during this transition.

An important factor to remember is that any successful farming operation is a complex and unique system. It is not possible to change one component of the system without affecting other components. Consequently, the choice to leave more crop residues on the soil surface entails substantially modifying the present system or developing an entirely new one. If these changes are not made, it is highly unlikely that the system will work properly. It will either fail to take advantage of the full potential offered by high-residue systems or, even worse, will result in substantial management difficulties. If an attempt is made to change from low-residue to high-residue farming simply by changing the amount or type of tillage used, it is somewhat like attempting to change from gasoline to diesel power simply by pumping the gas out and filling the tank with diesel.

So where does a producer start? The best place is to reflect on the current mode of operation. Why are things done in a certain manner by one producer while neighbors operate differently? Maybe the producer milks cows, has less available capital, or values fishing time more than the neighbor. These factors will not necessarily change. What is good or bad about the present system?

The next step is to study successful and unsuccessful high-residue systems that have been tried both in the immediate area and in other regions. Try to determine what makes the successful systems work and the poor ones fail. Resist the temptation to adopt someone elses system lock, stock, and barrel. It may work wonderfully for them but fail badly for you.

Obtain as much professional advice and information as possible. In other words, read the rest of this book and any others available. Attend seminars, field days, and workshops that focus on high-residue farming.

Do as much as possible the easy and cheap way by learning from other's successes and failures. In today's agriculture, a producer cannot afford to learn by making unnecessary mistakes. There is no single recipe that will allow all producers to successfully make the transition to high-residue farming. There are, however, some general broad categories that should be considered in determining how to make the transition. In the discussion that follows, these considerations are broken into economic, agronomic, and psychological categories.

Economic Considerations in Changing to a Surface Residue System

From an economic standpoint the best way to make the change to a surface residue system depends on each producer's ability to take risk, how well they have done their homework (as mentioned previously), their labor situation, the type of machinery owned, and whether or not the land is considered to be highly erodible. If a sufficient amount of planning is done, a producer can develop an improved system. Once a good system is designed, the quicker the change can be made the better. A quick change limits the amount of time two sets of equipment are owned, allows taking full advantage of an improved system more quickly, and will probably return a better trade-in value on unneeded equipment. This approach, however, carries with it more financial risk if a producer is not adequately prepared agronomically, economically, or psychologically for making the change.

A number of producers will choose to make the switch quickly for economic reasons other than those already mentioned. Some have land classified as highly erodible and consequently face substantial financial loss if they do not adopt conservation practices relatively soon. In this case the financial risk associated with not being in compliance may outweigh the risks involved in making the change quickly. Others may have reached the point where they need to trade equipment and wish to reduce the cost associated with this transaction. Some producers are facing a change in their operation that will require them to hire additional laborers if they continue to use tillage extensively. They may wish to make the switch to avoid the expense and time involved in training new laborers. Still others may wish to devote more time to other enterprises either on or off the farm.

Producers with less ability to take risks, less concern with highly erodible land, or less confidence in their choice of tillage, planting, cultivating, and spraying equipment may take a slower approach in changing over to a surface residue management system. This approach will generally entail renting appropriate equipment or hiring custom operators owning the equipment to perform the work that allows trying a high-residue system on a limited number of acres. The slower transition is more likely to be used in areas where there is insufficient research or experience available or examples to follow to allow producers to adequately design the agronomic aspects of their systems without some field testing. Moving slowly will allow the producer and the producer's partner, landlord, or banker to become more comfortable with high-residue farming. If the new system is first tested on a small portion of the farm, at least some of the parcels of land should be continuously treated with high-residue techniques rather than trying the technique on different parcels of land each year. As discussed more fully in the long-term effects chapter, many of the benefits of high-residue systems take several years to fully develop. Weaknesses in poor systems develop more quickly but may still not be evident the first year.

The main advantages of the "go slow" approach are really more related to agronomic and psychological considerations than to economic ones. The only benefit of going slow from an economic standpoint is to reduce risk. The slow approach reduces the risk associated with poor agronomic planning and allows the evaluation of machinery before purchases are made. While reliance on custom work and rented machinery reduces risk it generally increases costs. More importantly, many of the economic advantages associated with high-residue systems result from spreading the workload, better timeliness, and lower horsepower requirements—improvements that are not readily evident when only a limited number of acres are involved. This does not mean that there is no value in using the "go slow" approach but rather that these additional factors and their disadvantages should be considered.

Most producers are probably going to take an approach somewhere in between the "all at once" and "go slow" approaches. This will be directed toward quickly adopting a relatively simple, low-risk system. As soon as it is working properly they will begin to evaluate ways to fine tune and change that system to make it better. This middle-of-the-road approach is very similar to what most farmers do with their present practices, which are constantly being modified in an attempt to make them better.

Agronomic Conditions Affecting the Switch to a New System

Much information is published on the agronomic aspects of high-residue systems. Initially many of these data appear to be contradictory; some trials show one system or technique to be superior while others produce almost opposite results. The key to rationalizing these apparent discrepancies is to determine what different circumstances existed in the trials and why these caused the results that occurred. Soil analysis will produce understanding of why some practices work in some situations and fail in others.

The usefulness of a careful analysis is illustrated by the following example. Two tillage comparison studies conducted in central South Dakota produced apparently contradictory results. In the first study conventional tillage produced greater returns than no-till or minimum tillage. In the second study no-till returns were higher than minimum-till returns, and minimum-till returns were higher than conventional-till returns. Several differences in the management techniques contributed to the results. The most important was probably crop rotation. The first study used winter wheat-fallow and continuous wheat under the three tillage methods. The second study used wheat-soybean and wheat-corn-soybean rotations. Both studies took place in an area that receives 18.5 inches of precipitation on average annually. The rotations used in the first study led to significant yield losses from disease and weed problems when tillage was reduced or eliminated. Even if these losses could have been controlled, water use was not sufficiently intense to take advantage of the increased moisture that resulted from tillage reductions except in drier-than-normal years. The more diverse rotations in the second study limited disease and weed pressure resulting in reduced production costs. In addition the rotations used contained high-water-use crops that could take full advantage of the moisture saved by reducing or eliminating tillage.

So which tillage method is best? It depends on which rotation is used. Which rotation is best? It depends on which tillage method is used. The apparently conflicting results actually make perfect sense when these interactions are understood. A good comparison in these studies is between the best tilled system (wheat-fallow) and the best no-till system (wheat-corn-soybeans). Or even better, compare your present system against what could be done if less tillage allowed more-intense rotations.

In making the decision to switch to a high-residue system, some general principles of the system should be recognized. Several management considerations become more important once tillage is reduced. These involve rotation, competition, and sanitation and each are discussed in the text that follows. Almost all of the management problems reported to be associated with reduced-tillage systems can be traced directly to a failure in one of these categories.

Crop Rotation

The art and science of proper crop rotation was the cornerstone of agriculture until quite recently. Intensive tillage in conjunction with modern technology has allowed producers to move more toward monocrop (single-crop) rotations than was possible less than 20 yr ago. Most producers are at least somewhat aware of the benefits of crop rotation in limiting disease, weed, and insect pressure, but many lack experience in using this concept. Proper rotation can prevent most pest problems from getting out of hand and significantly reduce the reliance on chemical control methods. It is not uncommon for a well-managed no-till system that uses rotation properly to use less pesticides than a conventional-tillage system that does not use a proper rotation. On the other hand, no-till or some other high-residue system using a poor rotation will usually require more chemical inputs than the same rotation done conventionally.

Besides the pest management aspects of crop rotation there are other benefits that are less understood and probably under used. These include the potential for better management and use of water, improved workload spreading, and better control of the seedbed environment for good plant establishment of the succeeding crop. Workload spreading allows substantial reductions in labor, power, and machinery costs while improving timeliness. Producers with irrigation or those in areas that normally have adequate or surplus moisture will use this concept less than those in drier areas. The profitability associated with growing full-season (high-water-use) crops often makes it more feasible for irrigation farmers to concentrate on a few specific high-value crops. In dryland areas more diversity in crops is required to manage scarce water supplies, and the workload-spreading aspects of rotational planning can provide major benefits.

The use of rotations to better manage and use water has applicability to both humid and arid regions. Reducing tillage enhances water entry into the soil and saves water. That can be either good or bad depending on whether that increased moisture is put to beneficial use or allowed to become a management problem. Soil, depending on type, can only hold about 1–2.5 inches of available water per foot of depth before it begins to drain away. The ideal condition is to have the root zone fully recharged, but not overfull, when the crop begins to use water. When the soil can no longer hold additional water, problems can occur with leaching, denitrification, runoff, diseases, and inability to handle traffic.

A proper rotation, designed for the tilling system used, will make good use of the water available. The rotations that have traditionally been used under conventional tillage are appropriate for the water conservation aspects of that tillage system. That is why this match has been successful and popular. In some years it is a little too wet or a little too dry and the system doesn't work well, but in most years the relationship between water received and water used by the crop matches quite well. When tillage is reduced, additional soil water is saved and the frequency of years when it is too wet will increase unless the rotation is changed to use more water.

Failure to change rotation has led to the belief that no-till causes fields to be too wet. If proper rotations are used that will be true only when conventional tillage systems are also too wet. Cropping intensity and therefore water use can be increased by introducing more full-season crops into the rotation and eliminating fallow or perhaps substituting a nitrogen fixing cover crop in lieu of fallow. In more humid regions where rotations are already heavily dominated by full-season crops with conventional tillage, the options include double cropping or the use of a cool-season cover crop. Reduced tillage will only show advantages from a crop production standpoint in drier-than-normal years and may result in decreased productivity in wet years unless rotations are changed.

The example that follows illustrates how rotations can be designed around weather conditions and designed to make good use of water. A no-till producer wishing to grow corn in eastern North Dakota or northeastern South Dakota is less concerned with a lack of soil moisture and more limited by soil temperatures than a producer in central South Dakota who normally finds moisture much more limiting to corn production than lack of heat. Consequently, the first producer will probably plant much of his corn following low-residue crops such as soybeans while the producer in the drier area would use a higher residue such as a small grain to precede corn. Where weather is highly variable from year to year as is common on the Great Plains, it is usually wise to include some rotational sequences that do well in nontypical years. In other words the first producer in this example may plant some corn following wheat to provide some protection in a very dry year. However, in a cool, wet year this corn may not mature properly. Likewise, the central South Dakota farmer could plant corn following soybeans or sunflowers on a limited acreage. This would produce well in a wet year and be used for forage in a dry year.

Another aspect of rotation that needs careful study when adopting high-residue systems is the ability of each crop in the rotation to provide a good seedbed environment for the crop that follows. Another example involves the common practice of seeding wheat following corn using conventional tillage. This rotation does not work well in high-residue systems, since the amount and type of residue left by corn hinders proper seed placement and early growth of wheat and can lead to severe head scab infections during flowering.

Weed control provided by a rotation in a high-residue system is also important to consider. The main purposes cited for the use of tillage are to control weeds and create a favorable environment for crop growth. When tillage is significantly reduced or eliminated, a good share of this job must be done through a well-planned rotation. Designing such a rotation requires a producer to have a good understanding of the climate and soils involved on the farm and the conditions each crop prefers during its seedling stage and the rest of the growing season.

With conventional tillage the producer in the wetter, cooler, areas probably planted corn following wheat, which had been fall plowed. This system worked because there was sufficient moisture accumulated between harvesting the wheat crop and planting the corn crop to allow some soil water to be wasted with plowing. The producer ended up with a warm, moist seedbed and a soil profile that was full of moisture in most years. If corn was seeded behind soybeans in a conventional-tillage system, the corn often suffered from lack of moisture later in the growing season. In other words, with conventional tillage there was not enough moisture available to allow corn to follow soybeans due to the water wasted by plowing. In this same area, no-till corn following soybeans does, however, work well most years if the wasted water associated with tillage is eliminated or substantially reduced.

Sanitation and Competition

The other two management considerations in a high-residue system are sanitation and competition. These again are important in conventional farming but become more so when tillage is reduced. Sanitation refers to any practice that prevents weeds, diseases, or insects from being introduced or established on the farm. Preventing a problem is much easier and cheaper than dealing with it later on. Sanitary practices include using weed-free seed, cleaning equipment between fields, eliminating perennial and noxious weeds by spot treatment before they spread, controlling volunteer grain and weeds to prevent insects from laying eggs, and preventing weeds from going to seed as much as possible. Sanitation also includes some considerations more specific to high-residue systems, such as mowing grass along field borders and waterways before the grass produces seed or at least before the combine header has a chance to gather the seeds and spread them 30 ft into the field.

Plants rely heavily on their competitive abilities to survive. Anything that can be done to create an environment that gives the crop an advantage will significantly reduce the ability of weeds to compete. This includes such normal practices as planting good seed, using sound fertility practices, and using well-adapted varieties. Some practices that may help crops compete specifically in a high-residue farming system include using starter or pop-up fertilizers to assure a fast start, using seeding equipment with excellent depth control capabilities to assure uniform stands, increasing seeding rates from what is typical when more water is available, using rows that are as narrow as possible to develop an early plant canopy, designing proper rotations to create an environment that favors the crop, and most importantly doing an adequately uniform job of spreading chaff and crop residues at harvesting time. This last practice cannot be overemphasized. With the equipment available today, it should be possible to spread both straw and chaff evenly over the width of the header. Most custom harvesters have good straw and chaff spreaders, and the rest can obtain them if they want your business.

Most of the concepts discussed in the agronomic section of this chapter are not greatly different from those used with conventional tillage. The difference is that the systems are dissimilar. Some of the old limiting factors associated with conventional tillage (such as lack of soil moisture) become less dominant with reduced-tillage systems, and new ones take their place. The secret is to design agronomic components that allow a producer to take advantage of the strengths and minimize the weaknesses of high-residue systems.

Psychological Considerations in Switching to a New System

The last factor involved in making the change to high-residue systems is psychological. Some producers relish the challenge of making changes in their operations. It is one of the things they like about farming. Other's plan changes for the sole purpose of improving the bottom line. They do not necessarily enjoy the process but hope to enjoy the results. Still others choose not to make any changes in their operation until it becomes clear that what they are now doing is no longer feasible and change is necessary to survive. Most producers fall somewhere in between these categories. Often a farming operation contains several partners, each with a different philosophy. Consequently, as stated at the beginning of this chapter, each producer must decide what operational changes will be made and how and when they will be made. Producers should not feel pressured by what the neighbors are doing or by information given in farm papers. Instead, they should take an approach that will work for their operation. If a producer must make a decision slowly to convince grandpa, so be it.

No matter how change is approached, producers should expend the effort and gain the knowledge necessary to make the transition successfully. There will be problems. Mistakes will be made with the high-residue system, but we must keep in mind that mistakes were made with the conventional-till system too. Producers that run into a problem should keep in mind that residue on the soil surface did not cause the problem. Instead, some component introduced into the system caused the problem. If this approach is taken, a producer will sleep more comfortably and the transition will go faster and more smoothly.

As a general rule, good managers who are successful conventional-tillage farmers will probably be even more successful by using high-residue systems. In making the change to high-residue systems, producers must make careful observations, plan adequately, and have a positive attitude.

P.S. If you decide not to trade the plow or disk and instead park it under the trees, be sure to take off the tires because grandpa may till all the stubble fields while you're on vacation.

11 Compaction and Bearing Strength

J.K. Aase and J.L. Pikul

It is apparent to anyone who walks agricultural fields that repeated traversing of tractors, combines, and loaded trucks creates surface soil depressions. Wheel tracks are evidence that soil compaction occurs to some extent on the semiarid northern Great Plains. How serious is this soil compaction? Little work has been done on the effects of soil compaction as related to crop yields in the northern Great Plains to answer this question. However, there are a few studies that help illuminate the effects of wheel traffic on crop yields and soil conditions.

One study in northwestern Montana, near Conrad, was conducted to determine winter wheat yields and compaction effects across crop strips in a traditionally tilled fallow-crop rotation. Winter wheat yields in the areas obviously compacted by the tractor tires ranged from 23 to 62 percent of the field average. The area affected by wheel-track compaction was about 13.5 percent of the field. In an associated study, soil compaction was evaluated by measuring bulk density (mass of soil per unit volume of soil) and penetrometer resistance of clay loam and sandy loam soils. Results of this study showed that compaction could be detected by penetrometer measurements but not by bulk density measurements. Conclusions drawn from the study were that shallow tillage and seeding alone do not ameliorate wheel traffic compaction effects and that wheat yields are reduced in compacted wheel-track areas.

Often soil compaction is identified with primary and secondary tillage implements and associated wheel traffic. However, compaction can also occur in no-till farming systems. Concern has been expressed that no-till farming systems may promote a gradual increase in bulk density. North of Culbertson, in northeastern Montana, spring wheat grown no-till every year for the last 10 yr on a sandy loam has yielded 75 percent more grain than the five crops of wheat grown in a fallow crop sequence. Soil penetrometer and bulk density measurements showed that, except in the surface 2 inches, soil resistance and bulk density were significantly higher under tilled soil fallow-wheat than under no-till to a depth of about 12 inches. The two measurements in the tilled soil also indicated that soil resistance and density were the highest at about 4 inches deep, corresponding to the normal tillage depth. These findings are contrary to the usual expectation that bulk density and soil penetration resistance will increase under no-till conditions. They indicate that tillage, which we have traditionally perceived as creating more soil porosity, can have a long-term negative effect on porosity.

However, soil type, climate, tillage system, and crop residue left on the soil all need to be considered when evaluating the effect of tillage on soil compaction. On a clay loam 40 mi south of the above-mentioned sandy loam, after 13 yr of comparative cropping practices, bulk density was significantly higher under a no-till fallow-wheat rotation than under a conventional stubble mulch-fallow rotation. The measurement procedures were identical at the two locations. It appears that the greater residue production in the no-till, annual production on the sandy loam fueled more biological activity which helped keep porosity high. It appears likely that the annual cropping system coupled with no-till on the clay loam would have helped increase its porosity (see chapter 18 for further discussion of these relationships).

On a silt loam in western Nebraska it was found that winter wheat root penetration and root functions were similar under no tillage and moldboard plowed fallow conditions even though a dense-plow shear plane formed at 4 inches in the tilled soil. Winter wheat yields from the no-till and plowed soils were similar.

Tillage pans are probably the most common form of compaction in the northern Great Plains. Where tillage pans or other types of pans are limiting root depth, it is probably wise to rip through and disrupt the pans prior to switching to a no-till system. The long-term benefits of this ripping will be greater if traffic over the ripper tracks can be avoided until roots have stabilized the open structure. While this can be difficult to achieve under crop production, it is technically achievable while lands are in grass under Conservation Reserve Program (CRP) contracts. However, before touching the CRP land the owner or operator should always contact the local county SCS office to make sure the proposed action does not violate the conditions of the contract.

Research has shown that, contrary to common opinion, soil freezing and thawing fail to ameliorate soil compaction and that deep tillage may be necessary to break up high-density layers.

Compaction from tractors and combines may or may not be a serious problem, depending on how and when they are used. The northern Plains area receives about 11–15 inches of precipitation per year, peaking in late spring and early summer. Most tractor and combine work in the area is done in the late summer and early fall or early spring when the soil surface is relatively dry and the chance of compaction is therefore reduced.

However, repeated traversing of heavy equipment is bound to cause some compaction, and that effect is exaggerated when it is necessary to use field equipment on moist soil. Therefore, if possible, it is wise to confine wheel traffic to the same tracks rather than randomly travel over the field. This procedure helps reduce the area of the field that is compacted and helps avoid yield reductions due to compaction.

Stubble left on no-till soils during the winter catches and retains snow, providing in general a better soil water reserve for the following crop than is the case on bare soils. Depending on stubble height and soil water content in the fall, as much as 1–2 inches of soil water can be gained over winter under stubble compared to tilled bare fallow. Since the depth of the snow cover is no more and is usually less than the height of the stubble, wet soil conditions and runoff problems are minimal. There is usually enough time between snowmelt and spring tillage to dry the soil surface sufficiently so that bearing strength is adequate to prevent serious compaction from the use of heavy field equipment.

Surface residues on no-till soils also reduce evaporation from the soil. Therefore it is advantageous to maintain residue at least through the planting season. On soils with residues, light spring rains will then maintain a moist seed zone for 10–14 days longer than on soils with no surface residue. Seeding depth on soils with residues can therefore be reduced, and seeds planted beneath these residues will have a better environment for germination, emergence, and plant establishment.

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12 Residue Reduction

Donald Tanaka and Vern Hofman

Maintaining crop residue on the soil surface is a practical, effective method of controlling soil erosion and increasing soil water storage. Quantities of crop residue usually decrease from harvest until the seeding of another crop. Crop residue reduction or loss during the noncrop period is dependent on several factors that will be grouped into two broad categories in this chapter. The first category includes soil and residue factors and the second includes mechanical factors (tillage). Discussion on crop residue reduction will be limited to residues of small grains—spring wheat, winter wheat, and barley residues. While each factor may be discussed individually, these factors are not independent; a change in one factor often causes a change in other factors. Factors affecting decomposition of corn, soybean, and other residues are discussed in the companion publication on crop residue management guidelines for the North Central region.

Soil Factors

Soil factors of importance in residue reduction include water, temperature, pH, aeration, and available nutrients. In the northern Plains, water is the most limiting factor for residue decomposition immediately after harvest. Water is required for microbial activity and for diffusion of nutrients and byproducts during the breakdown of crop residues. In the field the water content of residues and soils changes during the day, and the most rapid changes occur near the soil surface. Water not only governs activity and survival of microorganisms but also influences soil and residue temperature, aeration, and nutrient availability in the soil. Table 6 illustrates how water can enhance residue reduction of a spring wheat crop after harvest. While the 1986 spring wheat crop produced almost twice the quantity of surface residue compared to that of the 1981 crop, the greater amount and frequency of precipitation after harvest greatly accelerated the rate of residue decomposition. Air temperatures were not significantly different in 1981 and 1986.

During the overwintering period between crops (November through April), temperature is the factor that controls the rate of residue reduction. Ideal temperature for maximum growth and activity of soil microorganisms is 68–95 °F, with bacteria and fungi dominating residue breakdown near and below 68 °F and actinomycetes dominating as temperatures approach 95 °F. During late spring and summer, residue decomposition progresses at a much faster rate because the soil water content and surface soil temperature are ideal.

Soil microorganisms differ in optimum pH for maximum growth and activity, but the optimum pH range for rapid decomposition of crop residue is 6.5–8.5. Most surface soils in the northern Plains have pH values in this range. Soil pH at microsites is dynamic and can change with aeration. In the northern Plains, aerobic conditions occur more often than anaerobic conditions; therefore, exchange of carbon dioxide and oxygen for microbial growth is usually not limiting for crop residue decomposition. Gas exchange can be limiting, however, if residues are not spread uniformly (for example, when large quantities of residue are concentrated in piles on the soil surface).

Residue Factors

Residue factors that influence rate of residue decomposition include crop type and chemical composition, position, and length or size of the residue. Residue reduction begins at the time of harvest. In general, wheat residue consists of about 70 percent straw (leaf blade, leaf sheath, and stem) and 30 percent chaff (glumes, spike parts, and small pieces of stems) by weight. As wheat grain yields increase from 900 lb/acre to about 4,500 lb/acre, straw-to-grain ratios decrease from about 3.1 to 1.0. After a combine is used to harvest the grain crops, the greater the stubble height, the less residue reduction will take place. Taller stubble means that more of the crop residue is standing rather than flat, and therefore less of the total residue has a chance to interact with the soil surface where moisture and microorganisms begin residue decomposition. An ideal stubble height maintains residue for long periods of time, reduces wind and water erosion, traps snow, and stores soil water, and is generally in the range of 8–12 inches.

Barley, spring wheat, and winter wheat residues differ in plant chemical composition and therefore have different decomposition rates. Current thinking is that residue decomposition proceeds sequentially with soluble carbon and nonstructural carbohydrates decomposing first, followed by cellulose and hemicellulose and then lignin, which degrades very slowly. The initial rapid weight loss of residue can be attributed to leaching of soluble carbon and nitrogen compounds and inorganic ions and to microbial decomposition. Residue loss attributed to the initial breakdown is usually 10–20 percent. The cellulose, hemicellulose, and lignin portions decompose at a constant linear rate. When the carbon/nitrogen ratio is lower, the amounts of soluble carbon and nitrogen are generally higher and decomposition is faster. The carbon/nitrogen ratios for small-grain residues are in the following order: barley<spring wheat<winter wheat. Therefore, barley would have more soluble carbon and nitrogen and would decompose more rapidly than spring or winter wheat, and spring wheat would decompose more rapidly than winter wheat. Table 7 shows that spring wheat residue breaks down faster than winter wheat, at least initially, after harvest.

Residues that contain more than 1.5 percent nitrogen usually do not need additional fertilizer nitrogen or soil nitrogen to meet demands of microorganisms during decomposition.

Residues with less than 1.5 percent nitrogen require additional fertilizer nitrogen or they will immobilize soil nitrogen at some point during the decomposition process.

Minimal information is available on the influence of crop residue size on rate and extent of residue decomposition in the field. With the current harvesting equipment technology, physical size or length of crop residue can be manipulated by using straw choppers, straw spreaders, and chaff spreaders to achieve the desired size for erosion control or seeding. Studies on pine sawdust (having particle sizes ranging from 0.01 to 0.20 inches and being mixed with soil) suggest that small cellulosic particles decompose faster in the first 30 days. To date, no published information is available on the decomposition of spring wheat, winter wheat, or barley residues of different size.

Burial removes residue from the surface and accelerates its rate of decomposition. Subsurface tillage implements such as V-blades and rodweeders do not invert the soil and bury the residue as completely as a moldboard plow does. However, any tillage equipment tends to bury some residue, and three or four passes with subsurface equipment generally buries most of the residue. For instance, after V-blades and rodweeders were used at Sidney, MT, only 17 percent of spring wheat residue remained on the surface for erosion control compared to 54 percent for no-till (table 7). For the 14-mo fallow period of winter wheat, similar trends were observed; 29 percent and 68 percent of the residue remained on the surface after 14 mo of fallow for conventional-till and no-till, respectively. Studies conducted where wheat residue was placed in fiberglass bags indicate that residue decomposition is the greatest when bags are buried, is less when placed on the soil surface, and is least when placed above the soil surface. Therefore mechanical tillage, or the lack of it, plays a major role in residue reduction.

Mechanical Factors

Most tillage practices reduce residue cover. The amount of residue lost varies considerably due to the type of implement, depth of operation and speed of travel. The purposes of tillage in the northern Plains are to control weeds, reduce residue, prepare the seedbed, incorporate fertilizer and pesticides, and dry out the soil (for fine-textured soils having shallow water tables). Current research and producer experiences, however, show that not all of these purposes are essential and that there are alternatives to tillage for achieving the others. Most weeds, for example, can be controlled with herbicides and crop rotations.

Many types of seeders are now available that will work in high residue conditions. Just what constitutes a good seedbed, however, is sometimes difficult to determine. If the seedbed is considered in terms of what conditions will cause most rapid germination and growth, warmth, moisture, and a firm seed zone would probably top the list. Under no-till conditions the seed-zone environment is usually moist and firm. In a no-till system the producer can plant seeds at a shallower depth than in a conventional-till system, and soil temperatures at the shallower depth are usually warmer in the fall. Although the soil may remain cooler longer in the early spring under no-till, the extra soil moisture saved by no-till will usually more than compensate for the effects on yield of cooler soil by reducing water deficiency later in the growing season when rainfall tends to decrease. In other words, slow growth in the early growing season will be more than made up for later.

In the northern Plains, soil moisture is usually available near the soil surface in the spring if surface residue cover is at least 50 percent. If spring tillage is necessary, it is best to keep it shallow to keep depth of soil drying to a minimum. Shallow tillage will usually control most weeds. Tillage for fertilizer and pesticide incorporation is often done in the fall and is especially common for anhydrous ammonia. The remainder of the fertilizer can usually be applied at seeding time with a drill in a one-pass operation that places fertilizer near the seed. Preemergence pesticides can usually be replaced with postemergence types, and some newer brands of seeders are capable of placing large quantities of fertilizer, including anhydrous ammonia, a short distance from the seed at planting time. In the Great Plains, it is extremely important to save as much moisture as possible to achieve maximum crop production.

The type of tillage has a major effect on residue cover. The approximate percentage of residue cover remaining on the soil surface after a single pass of various tillage implements and seeding equipment is listed in table 8. Many factors affect the amount of residue left after a pass with a tillage implement or seeding unit. Residue levels are sensitive to depth and speed of equipment operation and to the number and size of shanks or discs that are stirring the soil. When selecting values from the table for a specific machine, the producer should consider that: (1) shallower operating depths leave a greater amount of residue on the surface whereas deeper operating depths bury more residue and (2) slower operating speeds tend to leave more residues on the surface whereas faster speeds bury more residue. The ranges provided in table 8 are largely a result of variations in operating depth and speed. Usually the higher values of the ranges are appropriate at an operating depth of 2–4 inches along with a speed of 3–4 mph. If operating depths are 5–10 inches and travel speeds are 5–7 mph, the lower values are usually more accurate. Under some conditions, field cultivators, some other implements, and drills may return some residue to the surface that was incorporated at shallow depths by previous operations.

A chisel plow can leave as little as 20 percent or as much as 80 percent of the crop residue on the surface depending on the condition of the residue, the type of tillage point on the plow, operating speed, and operating depth. A chisel plow with wide low-rise sweeps operating at a low speed and shallow depth may be able to maintain a 70–80 percent cover. If one with twisted spikes, however, is operated 8–10 inches deep and at 5.5–6 mph, only 20–30 percent of the residue may be retained on the surface. An undercutter with a blade 24 inches or wider will usually leave 70–90 percent of the residue on the surface. A tandem disk with small blades operated at a slow speed (3–4 mph) and shallow depth (3–4 inches) may retain 50–70 percent of the residue. But a heavy disk with large blades 6–7 inches deep and operated at a fast speed (6 mph) may retain only 20 percent of the cover.

Estimating Residue Cover

Typically most fields will have 80–90 percent cover after harvest of a good small-grain crop. After a dry year cover can be much less. One means of estimating residue cover is to compare the amount of residue on the soil surface with pictures of surfaces with known coverage. The most commonly used method for determining percent cover, however, is the line-transect method. The following steps are involved in this method:

1. Select an area that is representative of the field, and stretch a 50- or 100-ft tape measure across the crop rows or tillage travel direction as indicated in figure 1. The tape measure should be laid across the rows at an angle of 45–90 degrees from the rows.

2. Position yourself directly over the first foot mark and look down. Determine whether the soil directly under that mark is covered by residue. Figure 2 illustrates which pieces of residue count as cover and which don't. On a piece of paper, record whether or not residue was covering the soil at the foot mark by scoring a 1 for "yes" and a 0 for "no."

3. Walk along the tape, and make an observation at each foot mark along the tape (that is, repeat step 2 at each foot mark). If you are using a 100-ft tape, you should record 100 numbers. Make all observations on the same side of the tape. Pieces of residue smaller than 3/32 inch have been judged too small to absorb the impact of raindrops and consequently should not be considered as cover.

4. If 100 observations were made in steps 2 and 3, the estimate of percent residue cover is equal to the number of points under which the surface was covered by residue. If 50 observations were made, multiply the number of points covered by residue by two to obtain the estimate of percent residue cover.

5. At least five lines (or five transects) should be made in each field (using steps 1 through 4 in representative portions of the field) to obtain an estimate of the mean that is within plus or minus 10 percent of the real mean.

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Table 6. Spring wheat residue reduction from harvest (August) until November as influenced by precipitation and temperature between August and November

Crop year	Precipitation (inches)	Air temperature (°F)	Residue reduction (%)
1981	2.93	58	10
1986	4.13	56	42

Sources: Adapted from Tanaka (1986) and Tanaka (unpublished data).

Table 7. Spring and winter wheat residue reduction during fallow as influenced by tillage at Sidney, MT

	Residue reduction (%)			
Crop and tillage method	Harvest to Nov. 1	Nov. 1 to Sept. 30	Oct. 1 to spring wheat seeding	Total
Spring wheat (21-mo fallow)				
Conventional Till*	10	65	8	83
No-till	10	23	13	46
Winter wheat (14-mo fallow)				
Conventional till*	6	65	--	71
No-till	6	26	--	32

*Conventional till involved one operation in mid to late May with a V-blade followed by two or three operations with a rodweeder as needed to control weeds.

Sources: Tanaka (1986) and Tanaka (unpublished data).

Table 8. Influence of tillers, seeders, and other equipment on the percent of residue left on the surface after one pass

Equipment	Percent residue left
Sprayer (chemical fallow)	100
Chisel plow with:	
Sweeps	50–80
Straight spikes	40–70
Twisted points or shovels	20–50
Undercutter with:	
V-Blade >30 inches wide	80–90
V-Blade 20–30 inches wide	70–80
Subsoiler	80–90
Chisel plow or coulter-chisel with:	
Sweeps	50–80
Straight chisel, 2-inch points	40–70
Twisted points or shovels	20–50
Disk-chisel plow with:	
Sweeps	45–60
Straight chisel, 2-inch points	35–55
Twisted points or shovels	15–40
Disk (tandem or offset) with:	
Blade less than 23 inches in diameter	40–70
Blade 23–28 inches in diameter	20–50
Blade over 28-inch diameter	10–40
One-way disk with:	
12–16 inch blades	40–50
18–30 inch blades	20–40
Single gang disk	50–70
Field cultivator	40–70
Harrows with:	
Springtooth	60–80
Spike tooth	70–90
Spring tooth with rolling basket	70–90
Rotary Tiller with:	
Secondary operation 3 inches deep	40–60
Primary operation 6 inches deep	15–35
Rod weeder with:	
Plain rotary rod	80–90
Rotary rod with chisels	70–80
Anhydrous applicator	75–80
Rotary hoe	85–90
Mulch treader	70–85
Drills with:	
Hoe-opener drill	50–80
Single-disc drill	80–90
Double-disc drill	70–80
Air seeder	50–80
Moldboard plow	5–10

Source: U.S. Department of Agriculture, Soil Conservation Service, and Equipment Manufacturers Institute (1992).

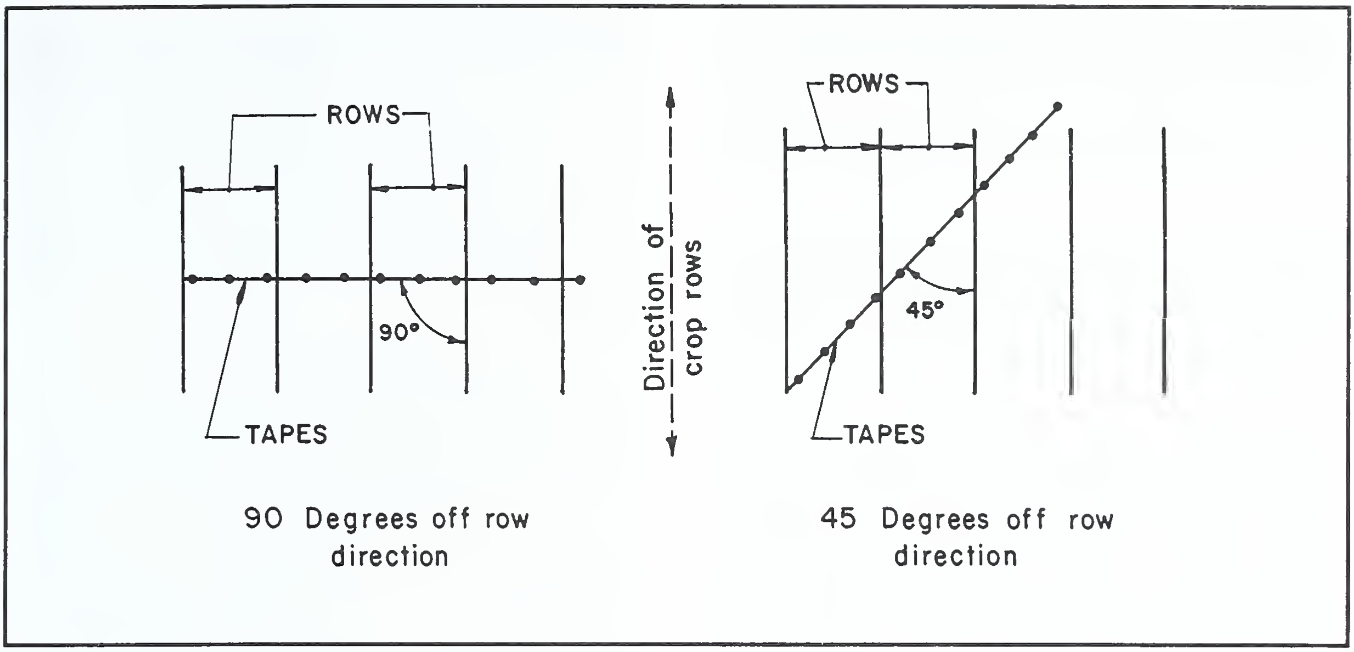

Figure 1. Orientation of tape measure to crop row direction

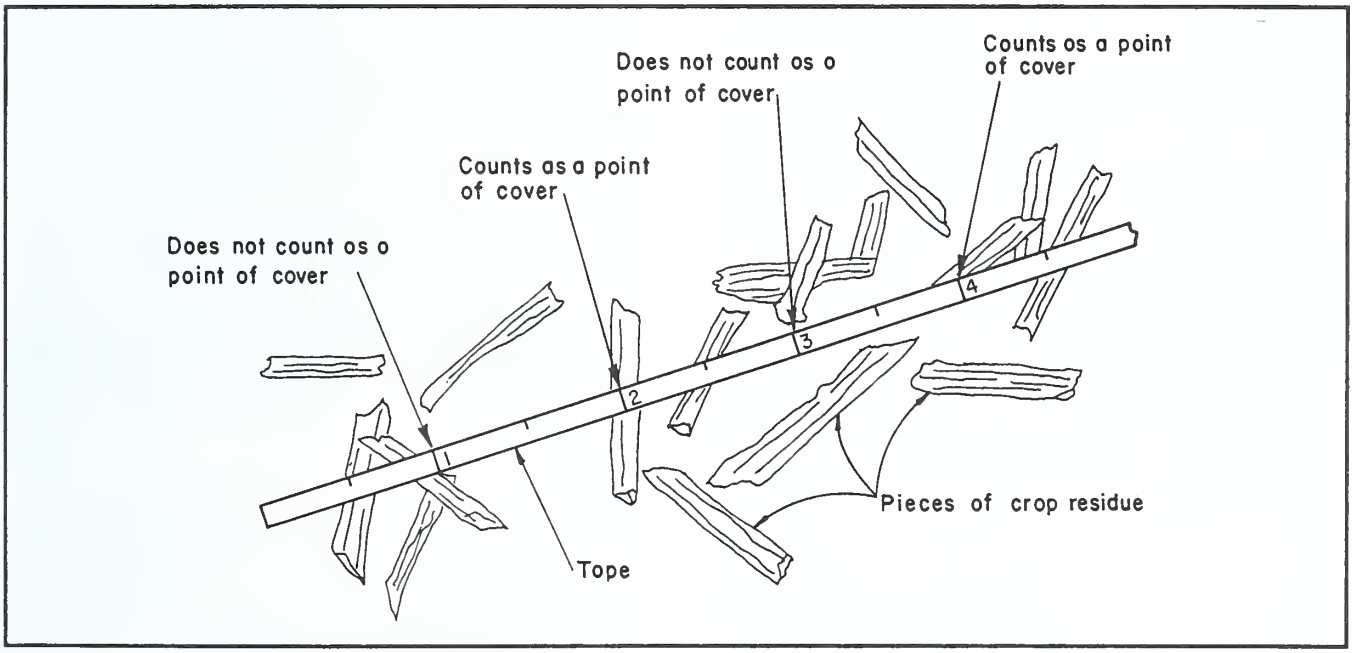
Does not count as a point of cover
Counts as a point of cover
Does not count as a point of cover
Counts as a point of cover
1
2
3
4
Tape
Pieces of crop residue

Figure 2. Illustration of how to determine whether a piece of residue "counts" when using the line-transect method to estimate residue cover

13 Weed Management in Reduced-Tillage Cropping Systems

D.J. Lyon, S.D. Miller, and G.A. Wicks

Conservation tillage practices are gaining in popularity because they reduce energy requirements and conserve and protect soil and water resources. However, concern about weed control still remains a deterrent to extensive adoption of this technology.

Weeds have been a problem in all cultural systems devised through the ages. Only the means of control and the specific weeds that are troublesome have changed. Weed management in reduced-tillage and conventional-tillage cropping systems is highly dependent on herbicides; however, effective management programs must also manipulate weed and crop associations to favor the crop at the expense of the weed.

Weed Management Strategies

A number of factors influencing weed management decisions, including weed identification, weed spectrum, preventative control, crop rotations, competitive crops, fertilization, tillage, and herbicides are discussed in this chapter.

Weed Identification

Early weed identification should be the first step in an effective weed management program. Accurate weed identification is important for effective and economical weed management decisions. Many weeds look similar in the seedling stage; however, the means to control them may be quite different. For example, wild buckwheat and field bindweed are often confused early in the growing season, but field bindweed, a perennial, requires a different control program than wild buckwheat, an annual.

Mapping weed locations in a field can greatly aid weed management decisions. Knowledge of current practices and weed history provides valuable information for designing improved weed management strategies and for keeping track of weed spread. Perennial weeds such as Canada thistle and quackgrass, which are difficult to control, usually occur in patches. Scattered patches and individual weeds can be spot treated with an herbicide, rogued (pulled out by hand), or cultivated. Many annual weeds such as jointed goatgrass can move into the field from roadsides.

Weed Spectrum and Populations

Control of existing weed species is an ongoing problem associated with both conventional- and conservation-tillage systems, but perhaps a more important consequence of changing to reduced- or no-tillage systems is the potential for shifts in weed species composition. A change in tillage system may promote the emergence of a weed species that may be tolerant of common weed control practices. In other words, when a particular combination of weed control treatments is chosen, certain weeds will be favored. The most common observation relative to weed shifts under reduced-tillage systems is that populations of annual weeds may be reduced but perennial weeds tend to become more prevalent.

Several factors contribute to changes in weed populations under reduced-tillage. Changing tillage practices most immediately impacts the vertical distribution of seeds in the soil profile, and this distribution can affect weed plant density and species composition. The response to burial of individual weed species differs, which can give a selective advantage to certain species. The most common observation relative to this is that in a winter wheat-fallow rotation, winter annual grasses such as jointed goatgrass and downy brome grass are favored in reduced-tillage systems. In addition strong selective pressure placed on weed populations by herbicides can contribute to weed species shifts.

Preventive Control

Preventive weed control does not involve large additional costs, specialized equipment, or other resource inputs. This method of control does, however, require good management. Weed-prevention methods include such things as planting clean weed-free seed, using weed seed screens or traps to filter weed seed and propagules out of irrigation water, using proper field and ditchbank sanitation, cleaning farm implements when moving from field to field, preventing weeds present in a field from producing seed, composting manure before spreading, and avoiding movement of livestock from weedy fields to weed-free fields without allowing time for weed seeds in their intestinal tract to be discharged.

If producers buy and plant certified seed, the chances of introducing weed problems into a field are lessened. There are, however, many growers who save their small-grain seed for planting next year's crop. The potential is high for such seed to contribute to increased weed problems (that is, jointed goatgrass, volunteer rye, wild oat). If weed seeds are added to the soil with the crop seed, they will be in an ideal location to germinate and grow because they will be close to the soil surface, in the disturbed drill slot, and close to the applied fertilizer. If the producer purchases and plants seeds that contain a weed species not already present in the field, this mistake may require costly control in the future.

Careful management of field margins is an effective method of reducing weed-control costs and frustrations in reduced-tillage cropping systems. Field margin species that have been particularly troublesome in reduced-tillage systems include quackgrass, foxtail barley, smooth brome grass, jointed goatgrass, false chamomile, prairie wild rose, leafy spurge, milkweed spp., roundleaf mallow, and common tansy. Obviously the control method selected should be based on the species, location of the infestation, and local conditions. There is often more than one solution to any weed problem. Control techniques could include strip tillage, selective herbicides, sterilants, mowing, or a combination of techniques to form an isolation barrier between the field and the source of the weed problem. The width of the isolation barrier will be influenced by the species to be controlled but in most cases should involve less than 1 percent of the total field area. Field margin sanitation will generally require operations separate from normal field management and therefore must be planned carefully.

Crop Rotations

A crop rotation is a planned sequence of crops grown in succession on the same field over an extended period of time. Rotation is useful because continuous and uniform management practices select for those weeds that are best adapted to the particular management system. Each crop and management system tends to develop its own characteristic weeds. Crop rotation leads to the diversification of individual cropping practices, each of which offers opportunities for control of different groups of weeds. The more dissimilar the crops and their management practices are in a rotation system, the less opportunity an individual weed has to become a problem.

Crop and herbicide rotation is an effective component of an integrated weed management system. Since herbicide selection to control all weed species is difficult, crop rotations allow the use of different herbicides so that a weed species does not go uncontrolled for several seasons in a row.

Competitive Crops

Getting a crop to grow vigorously is often the most effective and economical weed control practice available. The potential contribution of crop competition to weed control is often overlooked. Smother crops are crops that are especially competitive with weeds and by themselves keep weeds in check. They generally are solid seeded or planted in closely spaced rows. Examples of smother crops are alfalfa, millet, rye, sudangrass, sweetclover, and soybean for hay.

Smother crops are not the only crops with sufficient competitive ability to yield substantial weed control. All other forage and small-grain crops, perennial grass sods, and most agronomic row crops can provide heavy competition if managed correctly. Shading is the major means by which crop plants suppress weeds. The crop must have optimum stand establishment and develop rapidly enough to get ahead and stay ahead of the weed. Any plant-related factor or management practice that hastens shading by the crop favors the crop and enhances its competitive ability. Emerging from the soil first, having a height advantage, or growing at a faster rate than the weed are factors that provide a competitive advantage to the planted crop.

Crops can be manipulated and managed to optimize shading ability. Several cultural practices such as optimum plant arrangement, smaller distance between rows, and higher seeding rates maximize shading by hastening crop canopy closure. Selecting well-adapted, fast-growing varieties further favors the crop. Varieties differ in their ability to compete with weeds. Further, the highest yielding varieties are not necessarily the most competitive. Competitive varieties have been identified in several crops, including wheat, corn, sorghum, and soybean. Other conditions that favor the crop are timely planting, irrigation, and control of other plant pests.

Fertilization

Soil fertility can be managed and manipulated to optimize crop competitiveness. Manipulation of phosphorus and nitrogen appear to offer the greatest potential. For example, broadcast nitrogen applications in a winter wheat-fallow rotation have increased downy brome grass populations when compared to unfertilized treatments. In addition broadcast nitrogen doubled root growth, tripled shoot growth, stimulated earlier spring growth, and increased root depth of the downy brome grass. However, nitrogen placement has an effect on the population of this grassy weed. Significantly fewer downy brome grass plants were observed in banded, as opposed to broadcast, nitrogen treatments, and the wheat crop used more nitrogen and produced more grain with banded rather than broadcast treatments. Similar research in Canada indicated that phosphorus placement influenced barley and wild oat response. Drilling phosphorus with the barley seed increased phosphorus uptake and barley grain yield without causing similar increases in phosphorous uptake and grain yield of wild oat, which was distributed randomly in the plot.

Cultivation

Although row crop cultivation is not generally part of reduced-tillage systems, certain types of cultivation can be effective for weed control in these systems. It is important for the cultivation to maintain a large portion of the residue on the soil surface to prevent soil losses by erosion. Cultivators should be equipped with sweeps that undercut the weeds but leave a significant amount of residue on the soil surface.

Very little soil erosion will occur from crop cultivation if cultivation is done during periods of reduced rainfall intensity and frequency and when crops are providing a partial canopy. However, in concentrated water flow areas where soil is frequently eroded to the depth of cultivation, herbicides are the means of weed control most compatible with soil conservation.

Herbicides

If a producer converts from a conventional-till system to a reduced- or no-till system, greater demands are placed on weed control methods other than tillage to maintain adequate weed control. In some situations higher herbicide input levels have been required to overcome the increased weed competition in reduced-tillage compared to conventional-tillage systems. However, herbicide inputs can be lowered in a conservation tillage system by implementing a diversified crop rotation.

Burndown herbicides. These herbicides are often applied prior to planting in reduced-tillage systems to control emerged weeds. The ideal burndown herbicide kills the weeds quickly and does not leave harmful residues in the soil. Currently two herbicides fill the above requirement. Paraquat and glyphosate are nonselective herbicides that have no soil activity and may be applied before or after planting but before crop emergence of wheat, corn, sorghum, sunflower, and soybean. Paraquat is a very rapid acting contact herbicide whereas glyphosate is a slower acting translocated herbicide.

Generic names are used for herbicides discussed in this chapter. Table 9 links the generic names to the trade names under which these herbicides are sold.

Early preplant (EPP) herbicides. These herbicides are applied several weeks to several months prior to crop planting and have proven to be particularly effective for managing weeds in conservation tillage systems. Advantages of EPP herbicide application include prevention of weed establishment, elimination of the need for burndown treatments at planting, and reduced potential for herbicide carryover from one crop season to the next. Effective early preplant herbicides for use in corn include alachlor, metolachlor, atrazine, cyanazine, and various combination treatments (mixtures of these chemicals). EPP herbicide rates are approximately one-third higher than the rates used for herbicides at planting.

Preplant surface applied (PPSA) herbicide treatments. These treatments are applied 0–10 days before planting. Some planters have deep tines or coulters that stir up soil from depths not reached by PPSA and EPP herbicides. Weed seeds in this deep untreated soil may be brought near the surface by these planters, where they will germinate and grow in the rows unless there is a residual herbicide in the soil.

Preemergence (PRE) herbicide treatments. These treatments are applied from planting time to just before crop emergence. Surface mix (PRESM) is the shallow mixing of a PRE herbicide into the top 1 or 2 inches of soil using a rotary tiller, mulch treader, field cultivator, or similar implement. Weed control with PRE treatments may be poor if there is no rain to move the herbicide into the top inch of soil. To overcome dependence on rainfall and to increase dependability, some PRE herbicides may be incorporated into the surface soil with a rotary hoe. Excessive rainfall may leach some of the more soluble PRE herbicides, especially on sandy soils.

Postemergence (POST) herbicide treatments. These treatments are an important component of reduced-tillage cropping systems. Herbicides used for POST treatments must be specifically able to kill the problem weeds without damaging the crop. For some crops these herbicides may be limited, expensive, or nonexistent, which can be a major impediment to development of reduced- and no-till systems. Therefore, in planning weed management programs for reduced-tillage cropping systems, the weed problems must be identified and the crop rotation selected to allow for adequate herbicide application. Environmental factors that promote plant growth (for example, adequate water supply) generally enhance weed control with POST herbicides.

Herbicide carryover. If an herbicide persists and remains active it may damage crops planted the year following application. The carryover potential of an herbicide must be a primary consideration when selecting herbicides and crop rotations. Herbicide residues are most likely to occur following years with below-normal rainfall because chemical and microbial activity needed to degrade herbicides is limited in dry soil. Crop damage from carryover herbicide residues can be minimized by applying the lowest herbicide rate required for good weed control, by applying herbicide combinations rather than individual herbicides, by using band rather than broadcast applications, or by planting an herbicide-resistant crop.

Herbicides with the potential to carryover from one crop season to the next in the northern Great Plains include atrazine, chlorimuron, chlorsulfuron, clopyralid, ethalfluralin, imazethapyr, metribuzin, metsulfuron, pendimethalin, picloram, triasulfuron, and trifluralin. Producers should always check herbicide labels for crop restrictions and recommended intervals to be allowed before planting sensitive crops following use of specific herbicides.

Herbicide resistance. Resistance of weeds to herbicides has become a serious problem in many areas of the northern Great Plains. The weed spectrum in a field evantually shifts following the repeated use of the same selective herbicide. This shift occurs because susceptible weed species are eliminated and tolerant weed species increase in the absence of competition from the susceptible species. Likewise, individual plant species also have different plant types or biotypes in the population that vary in susceptibility to certain herbicides. Weed species that are very susceptible to certain herbicides may contain a small percentage of plants that are tolerant or resistant to an herbicide. Continuous exposure of the somewhat tolerant weeds to the same herbicide may gradually result in the buildup of the resistant biotypes. If the resistant types start to dominate the population, the herbicide is no longer effective on that weed species.

Various weed species have developed resistance to different herbicides. The most common incidence of herbicide-resistant weeds occurred with the triazine herbicides, atrazine and simazine. More recently, several weed species have developed resistance to chlorsulfuron and metsulfuron and all other herbicides with the same mode of action.

Herbicide-resistant weeds are most likely to develop with the repeated use of effective, long-residual, herbicides that kill susceptible plants by affecting a specific plant process. Resistance to both the triazines and chlorsulfuron developed in this way. The weeds most likely to develop resistance are those that are highly variable and that have a rapid life cycle with short seed dormancy, such as kochia and Russian thistle.

Resistant weed population development can be prevented by using crop rotations, herbicide rotations, herbicide mixtures of chemicals with different modes of action, and other integrated weed management practices.

Integrated Weed Management

The application of many technologies in a mutually supportive manner is commonly called integrated weed management. This management technique includes the selection, integration, and implementation of effective weed-control practices with due consideration of economic, ecological, and sociological consequences. Use of weed-free crop seed; use of proper crop rotation, seeding rate, row spacing, fertilization, planting date, cultivar selection, and field sanitation; and judicious use of herbicides are all practices that fit well into this concept. Sound agronomic practices help prevent shifts in the weed species found in a field and the development of resistant weed populations. Failure to use sound practices can mean the difference between success and failure in reduced-tillage weed management programs.

Weed Control in Corn

Several reduced-tillage systems for corn production are reviewed in this section; they include mulch till, stale seedbed, no-till, ridge till, and ecofallow. Suggestions for weed control in each system are discussed.

Mulch Till

The initial seedbed preparation in a mulch-till operation is usually done by a chisel plow or tandem disk harrow. During the second tillage operation, herbicides that require soil incorporation (such as butylate plus atrazine) may be applied. If herbicides are not applied during the second tillage, planting should be done within 7 days of the last tillage operation to ensure that weeds are not too large for control by PRE herbicides (applied just after planting).

Mulch-till leaves a seedbed suitable for rotary hoeing or other cultivation to control weeds after corn planting. Rotary hoeing should be done when the weeds are in the white stage, usually about the time of corn emergence. Rotary hoeing is difficult if crop residue is greater than 30 percent. Corn should be cultivated one to three times depending upon weed species and density. The first cultivation is done at about the seven-leaf stage depending upon soil conditions, weed density, and weed size.

PRE herbicides should be selected based on weed species present, cost, residual period, and carryover potential. New POST herbicides, nicosulfuron and primisulfuron, have greatly improved control of shattercane in corn.

Stale Seedbed

Following fall or summer harvest, initial seedbed preparation is made by a chisel plow or tandem disk harrow. In the spring the seedbed is prepared as soon as possible. At that time a preplant incorporated or nonincorporated herbicide should be applied. The seedbed is then ready to plant when the opportunity permits. Additional herbicides need to be applied to control weeds that emerge after the seedbed is prepared and to provide PRE weed control. There are several herbicides that could be used POST depending upon weed species present.

No-Till

No-till corn may be planted into residue of corn, soybean, sorghum, or small grain. Alfalfa and perennial grass are also suitable for no-till seedbeds. Herbicides are used to control weeds and they may be applied EPP, PPSA, or PRE. Alfalfa should be sprayed with dicamba in the fall. Split herbicide applications are often necessary, since weeds appear over a wide period of time and most herbicides do not control all weed species.

EPP herbicides, applied before weed emergence, allow the producer to avoid the use of burndown herbicides. If controlled early, weeds will not use appreciable amounts of soil water or nutrients. EPP weed control is more consistent than other methods of control because it is normally accompanied by timely rains that help incorporate the herbicide. One disadvantage of EPP herbicides is that they may break down before the peak germination period has passed. Rainfall or prolonged dry weather may hasten herbicide disappearance. After an EPP application and planting have occurred, a split application of a PRE or POST herbicide is necessary for season-long control.

Delaying EPP herbicide application until planting time may mean that only one application is necessary. Generally weeds are still small if corn planting is not delayed so risk of soil water loss is reduced. Usually paraquat, glyphosate, or glyphosate plus 2,4–D need to be added to the PRE herbicide to control emerged weeds. If grasses are the main problem, the producer should choose glyphosate. Glyphosate plus dicamba should be used if triazine-resistant kochia is also present.

EPP herbicide treatments generally provide the most satisfactory weed control when residual herbicides are applied 10–35 days before planting. Winter annual weeds should be controlled in April to prevent soil water loss and weed-seed production. A split herbicide application with a portion applied EPP and a second increment at planting will improve length of weed control. The split application could be helpful with short-residual herbicides or in situations in which heavy rains or delayed planting occurs following the first treatment. EPP treatments can often provide satisfactory weed control at a lower cost than treatments at planting time. Soil disturbance by the planter following an EPP or PPSA treatment, however, may allow weed growth in the row.

PRE herbicides such as atrazine, cyanazine, or cyanazine plus atrazine applied to annual grasses less than 1 inch tall and annual broadleaf weeds less than 4 inches tall may need additions of crop oil concentrate or urea ammonium nitrate to provide adequate control. In corn, 2,4–D ester may also be added for improved weed control. A POST herbicide such as glyphosate or paraquat should be mixed in with the PRE herbicides if grass weeds are 1–4 inches tall and the crop has not emerged. If grasses are taller than 4 inches and are growing vigorously, glyphosate should be applied at 0.38 lb/acre.

Ridge Till

Furrow-irrigated corn leaves an ideal seedbed for ridge till. The final tillage operation before irrigation moves soil into the corn row, thereby building a ridge. Water will move down the furrow between the rows. In the spring, stalks are chopped. If winter annual weeds such as tansy mustard or downy brome grass are present, they should be controlled with appropriate herbicides in the spring. Most early germinating broadleaf weeds can be controlled effectively and economically with 2,4–D. If corn planting is delayed beyond May 1, early germinating summer annuals must also be controlled.

With good management the ridge-till system has fewer weeds in the row than mulch-till systems because weed seeds produced the preceding year are not worked into the soil when the seedbed is prepared. During planting, sweeps or disks move soil containing corn kernels and ears, sorghum seed and heads, and about 80 percent of the weed seed from the ridge to the interrow. Corn is planted with planters designed to move 2–3 inches of soil from the ridge into the furrow. Sweeps or disks must be wide enough to ensure that weeds on the sides of the ridges are cut off or covered with soil. This allows the opportunity to use a band application of herbicide plus cultivation to control weeds between the rows. If timely cultivation is not possible and weed density is expected to be heavy or if the field contains many hard-to-control weeds like velvetleaf, a PRE herbicide treatment should be used. It also may be necessary to use a POST herbicide later.

Weeds like kochia and Russian thistle are troublesome if not killed before planting the crop. If not killed by the cutting edge of the planter sweep, larger broadleaf weeds may not be uprooted or covered with soil. Another option would be to cultivate the interrows and rebuild the ridges 2–4 wk before planting. This works extremely well on fields in which the previous corn crop was ensiled. Preplant cultivation also may be considered if ridges have been damaged by harvest equipment or livestock trampling.

Ecofallow

Ecofallow is a name commonly used for a weed and crop management system involving winter wheat the first year followed by corn the second year and fallow the third year. Farmers should grow winter wheat varieties that are high yielding and competitive with weeds, resist shattering, do not lodge, and have good disease and insect resistance. Also they should plant at the optimum date, fertilize according to needs, control weeds in the growing wheat, harvest with minimum grain loss, and distribute chaff and long straw uniformly.

Following the harvest of winter wheat, weeds need to be controlled within 30 days to prevent weed seed production and soil water loss. At this time the weeds are smaller and easier to control with glyphosate and paraquat. If weeds are under drought stress and the straw has settled, delay spraying until a week after rain. Glyphosate is most effective when applied before weeds reach the seed production stage. Paraquat is most effective in controlling small annual grass weeds as they approach maturity. Use a mixture of atrazine (16–32 oz/acre) and glyphosate plus 2,4–D (54–86 oz/acre) or use paraquat (6–8 oz/acre), depending on weed species. If grasses recover from initial after-harvest herbicide application, use glyphosate to kill those remaining. Producers should check with their own state Agricultural Extension Service concerning the legal application rates for their state.

In July and early August volunteer winter wheat, downy brome grass, and jointed goatgrass are not usually controlled with atrazine treatments. After the wheat crop is havested, a split application can be made. Immediately after wheat harvest, glyphosate plus 2,4–D should be applied; then in late August or in September an application of atrazine or a mixture of atrazine (1–2 lb/acre) plus glyphosate plus 2,4–D should be made. Lower rates of atrazine (or none) should be used on eroded areas, on soils with less than 1.2 percent organic matter, on soils with a pH of 6.8 or greater, on some terraces, on Canyon and Rosebud soils, and on caliche outcroppings. High-atrazine rates (that is, 2–3 lb/acre in the corn or sorghum years of a winter wheat-corn-fallow or a winter wheat-sorghum-fallow rotation and 1 lb/acre in the fallow year of a winter wheat-fallow rotation) on a field may carryover and destroy wheat on these areas in the following year.

During March and up until planting, fields should be scouted for weeds. Weeds need to be controlled with EPP applications to prevent loss of soil water. During this time atrazine, cyanazine, cyanazine plus atrazine, metolochlor, or metolachlor plus atrazine may be applied. Alachlor and alachlor plus atrazine can be applied within 7 days before planting. If fall applications of atrazine were made, maximum spring rates of atrazine should not exceed 0.5–1 lb/acre. The rate, however, depends upon the soil.

Planting is done with a no-till planter. Some planter units are set to remove straw and some soil over the row. This soil disturbance may remove sufficient herbicide that weeds are allowed to germinate and grow in the disturbed area. A PRE herbicide applied in a band or broadcast is necessary to control these weeds.

Triazine-resistant kochia and pigweed are present in many areas. Dicamba and dicamba plus atrazine are the most popular herbicides to use EPP, PPSA, PRE, or early POST for the control of triazine-resistant kochia. Kochia should be sprayed before it is 3 inches tall.

If grasses are 1–4 inches tall before planting, paraquat or glyphosate should be added to the PPSA treatment. If grasses are taller than 4 inches and are growing vigorously, apply glyphosate alone. In weedy fields the producer should consider banding an herbicide over the row during planting to kill weeds that will otherwise germinate from seeds brought near the surface by the planter.

The spring small grains are not as competitive with weeds as winter wheat. This is because the winter wheat is established in the fall and starts growth early in the spring before most weeds germinate. In good stands of winter wheat, most weeds except for winter annual weeds are not a problem.

The quantity of winter wheat stubble and straw may be greater and longer lasting than that of the spring grain crops. High levels of wheat stubble and straw can be effective in suppressing weeds. Therefore, planting crops no-till into the previous year's small grain may be successful or it may be a disaster if the herbicide treatments are not timely, properly selected, applied properly, and evaluated properly to determine whether retreatment or other weed control measures are necessary.

A critical part of the ecofallow program is weed control after spring small-grain harvest. A timely herbicide treatment after harvest prevents the weeds from producing seed and from using stored soil water. The herbicide treatments used for winter wheat after harvest can be used in small-grain stubble in most situations. The higher labeled rates of herbicides are usually required; thus, herbicide carryover may be a problem. Producers should consider extending the crop rotation by planting sorghum or another corn crop. Glyphosate and glyphosate plus 2,4–D are usually the nonselective herbicides of choice for control of emerged summer annual grass weeds that are growing rapidly. As weeds approach maturity, application of paraquat combined with atrazine has given good results. If atrazine is used after harvest, the next crop planted must be tolerant to it at the rate used (check the atrazine label).

The spring herbicide treatment is necessary. Again, producers should consult the label for proper herbicide rates for the crop that will be planted. If a residual herbicide was applied the previous fall, the soil should not be disturbed.

Weed Control in Soybean

Several reduced-tillage systems for soybean production are reviewed in this section; they include mulch till, stale seedbed, ridge till, and no till. Suggestions for weed control in each system are discussed.

Mulch Till

Weeds must be controlled in a timely manner with tillage and herbicides. The initial seedbed preparation for soybean is usually done later than for corn, thus allowing more weed growth. Therefore, chisel plowing or tandem disk harrowing may miss some weeds. Surviving weeds must be controlled before the soybeans are planted. Additional tillage should be done before planting to control small weeds and finish preparing the seedbed. At this time preplant herbicides may be applied or herbicide application may be delayed until after planting.

Rotary hoeing and row crop cultivation are effective for weed control except in wet weather. Soil should not be moved to the soybean row unless it is needed for weed control. Too much soil in the row can cause more harvest loss.

Stale Seedbed

The initial seedbed is prepared after crop harvest. In the following spring, 1–2 mo before planting, herbicides such as trifluralin and chlorimuron plus metribuzin should be incorporated 1–2 inches deep as the final seedbed preparation is made. If trifluralin is used alone, it should be incorporated 2–3 inches deep. Additional herbicides will need to be applied when the EPP herbicides begin to lose their effectiveness.

Ridge Till

Weed control for ridge-till soybeans is similar to that for corn except soybeans are commonly planted about 2 wk later. Delaying planting until mid-May allows early germinating weeds to grow vigorously. Weeds growing in the row quickly remove soil water. If the soil is too dry, planting may have to be delayed because soybean seeds may not germinate until the next rain. Large weeds are difficult to uproot and smother with soil when using a ridge-till planter. These weeds can be controlled by applying an herbicide EPP by mid to late April. A split application with two-thirds of the rate applied EPP and one-third of the rate banded over the row at planting will reduce the presence of large weeds at planting and extend weed control longer into the growing season than if the herbicide was applied as an EPP treatment alone. Another strategy is to apply glyphosate or paraquat before weed growth exceeds 2–4 inches in height (in late April to early May) and then apply a PRE herbicide at planting. Weeds such as Russian thistle, kochia, horseweed, smartweed, lambsquarters, and winter annuals will warrant an EPP treatment. Velvetleaf and grasses will emerge about May 1 in some years. Knowledge of weed emergence times is essential to ensure that herbicide application is timely.

Cultivation is necessary to control weeds between the rows and to rebuild the ridges for the next crop. Some harvest loss will occur because seed set is lower to the ground.

No-Till

No-till soybean production usually follows corn, sorghum, small grain, or soybean. EPP herbicides should be applied about 30 days before planting. Horseweed, winter annuals, kochia, and Russian thistle are problem weeds in the northern Plains, so proper herbicide selection is important. Glyphosate, glyphosate plus 2,4–D, or paraquat should be added to the EPP application to help control emerged weed species. Additional herbicides need to be applied PPSA, PRE, or early POST to maintain weed control.

Although narrow row planting of soybean promotes early canopy closure and consequently improves weed control, it has not been found to increase soybean grain yields in the semiarid northern Plains. Also, narrow row planting does not allow producers to mechanically cultivate weedy fields. Narrow row planting of soybean is not as common a practice in the northern Plains as it is in the north central region. Producers near that region may wish to read the north central region Crop Residue Management Report which is available through the Conservation Tillage Information Center in West Lafayette, IN.

Weed Control in Small Grains

Small grains, particularly wheat, play a vital role in conservation tillage systems in the northern Great Plains. Several rotations involve small grains in reduced-tillage systems; these rotations include winter wheat-fallow; winter wheat-corn, sorghum, millet or sunflower-fallow; barley-winter wheat-sunflower; spring or winter wheat-corn or soybean; and continuous wheat. Wheat is a key crop in these rotations.

There are two generally accepted reduced-tillage systems for small-grain production. These two systems, stubble-mulch and no-till, have been modified and hybridized across the northern Great Plains to meet the needs of farmers. Regardless of the system used, weed management should be emphasized throughout the rotation. Stands of vigorous wheat will effectively compete with weeds. Timely weed control, fertilizing (if needed), proper seeding, planting during the optimum time, and selecting a competitive variety will offer the winter wheat the best chance of reducing weed population and weed vigor after harvest.

Broadleaf weeds growing in the winter wheat crop may be controlled with POST applications of 2,4–D alone or in combination with dicamba, bromoxynil, metsulfuron, or triasulfuron. These applications should be made between tillering and the boot stage of wheat development. Dicamba should not be used with spring wheat, barley, or oat. Oat is very sensitive to many herbicides; only MCPA, bromoxynil, or 2,4–D amine should be used on oat. Although PRE herbicides such as triallate and trifluralin are labeled for downy brome grass control in winter wheat, the control they provide has been erratic, often ranging in the area of 50–80 percent control, and they do pose a risk of crop injury.

Stubble Mulch

The sweep plow is used for primary and secondary tillage in the stubble-mulch system. This plow effectively controls weeds if surface soils are dry and air temperatures allow for rapid wilting of the weeds. The sweep plow leaves a large percentage of the small-grain stubble on the surface and when carefully operated reduces residue cover only about 10 percent after each pass. See chapter 12 for further discussion of residue reduction.

The sweep plow must be used shortly after small-grain harvest before soils become so hard and dry that soil penetration with the blade becomes impossible. Rainfall in the late summer and fall may produce weed flushes that require additional tillage with the sweep plow. The benefits of additional weed control in the fall for moisture conservation must be weighed against the benefits of maintaining as much standing residue as possible over the winter months for soil erosion protection and snow catchment. Maximum residue retention over the winter months may be obtained by substituting after-harvest burndown herbicide treatments for fall-tillage operations. Tillage in the winter wheat-fallow rotation may begin in the spring or be delayed until June or later depending upon the need to control weeds or prepare a seedbed.

Several options are available for using nonselective herbicides after wheat harvest. With paraquat, be sure to use a minimum of 1qt surfactant/100 gal of solution. A surfactant should also be added to glyphosate (2 qt/100 gal of spray solution, or 0.5 percent v/v). Ammonium sulfate (spray grade) should be added to products containing glyphosate (for example, products that are a mixture of glyphosate plus 2,4–D or glyphosate plus dicamba) at a rate of 17 lb/100 gal of spray solution. Ammonium sulfate is especially important to add when the weeds are under stress. One cannot easily identify weeds under stress; therefore, it is wise to always add ammonium sulfate. A spray volume of 5–10 gal/acre should be applied to cropland when applying glyphosate, glyphosate plus dicamba, or glyphosate plus 2,4–D. Glyphosate plus dicamba will provide better control of kochia and Russian thistle than either glyphosate alone or glyphosate plus 2,4–D.

In the winter wheat-fallow rotation, atrazine plus 2,4–D combined with either paraquat or glyphosate is an effective after-harvest treatment if applied before weeds are too large. Glyphosate plus 2,4–D plus atrazine should be used on grasses in the boot stage. If weeds are mature, the combination of paraquat plus atrazine should be used. Glyphosate products should not be used on days for which rain or temperatures above 95 °F are predicted.

Split treatments have been especially effective for controlling weeds after harvest. The split treatment involves an application of glyphosate in July or August followed by a September application containing either a combination of atrazine, paraquat, and crop oil concentrate or atrazine alone. The choice of which second application to use is dependent on the amount and size of the weeds. The atrazine rate varies with soil and rainfall patterns. The applicator should be careful not to exceed the label rate for atrazine in applying the split treatments. The advantage of the split treatments is that they provide excellent control of volunteer winter wheat and other winter annual grasses.

The winter annual grasses such as downy brome grass, japanese brome grass, jointed goatgrass, and rye, have become more troublesome in reduced-tillage systems for winter wheat. One way to control these grasses is to till lightly after wheat harvest to help germinate their seed and then provide chemical or mechanical control after fall germination. Another very effective way of controlling these weeds in a reduced-tillage system is to introduce a late-planted spring crop into the rotation. This crop will allow time for the destruction of the weeds prior to their seed production.

Atrazine provides cheap residual weed control in the winter wheat-fallow rotation and allows the producer to avoid additional tillage or herbicide applications until the latter part of spring. After late spring, additional herbicides or tillage may be required. Tillage at this time will not result in as great a loss of residues and will be after the period of greatest soil erosion potential. Weed-control strategies during the fallow period prior to planting wheat will depend upon the amount of crop residue needed at seeding time and the number and types of weeds present. If residue levels are sufficient, primary tillage tools such as a sweep plow, tandem or offset disk, or chisel plow (with sweeps) may be used. If residue levels are low, herbicides should continue to be used during this period.

Weed control with the sweep plow is more difficult in the spring because soils are typically moist and temperatures are low. Weed control under these conditions may require burndown herbicides such as glyphosate or paraquat or more aggressive tillage, such as the use of a tandem disk harrow. While a disk will provide better weed control under moist and cool conditions, it will dramatically increase residue burial. In order to preserve residue, tillage during the summer can be restricted to those areas in the field where weed growth has become a problem.

The final one or two tillage operations prior to wheat planting should involve the rodweeder. This tillage tool provides good control of small weeds and can also provide a firm seedbed for wheat seeding. Tillage over the course of the fallow season should be done at increasingly shallower depths to ensure a firm seedbed for seeding wheat.

No-Till

Much of the early no-till effort in small grains was directed at continuous winter wheat and winter wheat-fallow rotations. Many problems were encountered, including substantially increased weed control costs and the population increases of some grassy weeds. For example, winter annual grass weeds such as downy brome grass and jointed goatgrass were a problem in rotations with winter wheat, and summer annual grass weeds, such as green foxtail and wild oat, were a problem in rotations with spring wheat. Although these results convinced many farmers that no-till does not work, a more appropriate conclusion is that no-till does not work without proper rotation of crops and herbicides.

Herbicides replace all tillage for weed control in no-till systems. The declining price of nonselective herbicides such as glyphosate over the last few years has made no-till small-grain production more economically feasible. The type and amount of herbicide used for weed control in no-till small grains will differ little from that described above for stubble-mulch systems as long as good rotations, sanitation, and competition practices are followed. The incorporation of late-planted spring crops in rotation with winter wheat keeps winter annual grass populations under control. Greater care in herbicide selection is required when small grains are grown in rotation with other crops to minimize carryover.

The principles behind no-till production of spring-seeded small grains (that is, barley, oats, and spring and durum wheat) is similar to those discussed for winter wheat. However, the timetable and specific weed problems differ. After spring-seeded small grains are harvested in late summer, perennial (for example, Canada thistle, quackgrass, and smooth brome grass) and winter annual (for example, field pennycress, shepherd's-purse, and flixweed) weeds should be controlled if they are present. Otherwise the weeds will be too big at seeding time in the spring (if rainfall is adequate to permit their growth) for effective burndown with glyphosate or paraquat. Glyphosate and dicamba have performed effectively in the fall. Generally, a burndown herbicide such as glyphosate or paraquat should be applied at planting time to control early emerging summer annuals (for example, kochia, wild buckwheat, and wild mustard). Subsequent POST herbicides should be applied in the crop as needed.

Weed problems in spring-seeded small grains are different than in winter wheat and include a combination of summer annual broadleaf (for example, wild mustard, wild buckwheat, redroot pigweed, common lambsquarters, and kochia) and grass weeds (such as wild oat and green and yellow foxtail). Not all weeds can be controlled with a single herbicide application because they have different emergence times. In addition application timing for several herbicides is different for spring-seeded vs. fall-seeded small grains, so the applicator should check the label closely for directions.

Weed Control in Sorghum

Mulch Till

EPP treatments that include cyanazine or cyanazine plus atrazine may injure sorghum if dry soil conditions between application and planting do not allow herbicide activation and subsequent breakdown to occur. To minimize injury, planting should be delayed at least 10 days after a soaking rain activates the herbicide. Triazine-resistant kochia should be controlled before planting.

No-Till

When the interval between herbicide application and planting is expected to be 28 days or more, split herbicide applications will generally give better control. Apply the EPP herbicide treatments followed by PPSA or PRE as time and needs dictate. If treatments are not applied until 14 days or less before planting, weeds will likely be emerged. If grasses are less than 4 inches tall, either add paraquat at 0.38 to 0.5 lb/acre or glyphosate at 0.38 lb/acre to the residual herbicides. Triazine-resistant kochia need to be controlled before planting.

Weed Control in Sunflower

No-Till

Only fields relatively free of weeds should be selected for no-till sunflower. All soil-applied herbicides currently registered for use in sunflower require incorporation, with the exception of pendimethalin for use in no-till sunflower. Pendimethalin should be applied EPP to increase the chance of catching a rainfall that will incorporate the herbicide prior to planting. If sufficient rain for incorporation is not received, this treatment will provide very poor control of weeds. Glyphosate should be used to eliminate weeds missed by pendimethalin before planting the sunflower crop. A split application of pendimethalin improves control. Sethoxydim is labeled for POST control of grass weeds in sunflower.

Great care should be used in selecting herbicides for use in crops preceding sunflower in the rotation. Sunflower is very sensitive to residual levels of atrazine and to many of the sulfonylureas such as metsulfuron and triasulfuron.

Minimum Till

A granular formulation of ethalfluralin has recently received labeling for use in a conservation-tillage system for sunflower production. This granular herbicide is applied with an air applicator in front of a V-blade sweep machine as early in the spring as possible. The early application increases the opportunity for sufficient rainfall to activate the herbicide. The sweep machine should be fitted with narrow (16- to 32-inch), flat V-blade sweeps to allow for shallow soil operation. Immediately prior to planting, the field should receive an additional shallow sweep operation, preferably at an angle to the direction of the original herbicide application. This tillage will provide more complete herbicide distribution and help kill any surviving weeds prior to planting and should leave 30–60 percent residue cover in a cereal grain-sunflower cropping system.

Other Sources

For more detailed information on the topic of weed control in reduced-tillage crop production in the northern Great Plains, the following resources are available from land grant universities in the region:

(1) NebGuides (from the Cooperative Extension Service, University of Nebraska) on:
  - Spring row crop planting and weed control in winter wheat stubble (G551)
  - Weed control in reduced-tillage corn (G123)
  - Weed control in no-till corn, grain sorghum, and soybean production (G899)
  - Annual broadleaf weed control in winter wheat (G853)

(2) North Dakota State University:
  - No till: Crop production basics (A–797)

(3) South Dakota State University:
  - No-till guidelines: For the arid and semi-arid prairies (B–712)

Table 9. Generic names of herbicides discussed in chapter 13 coupled with trade names used by distributors of these herbicides

Generic	Trade Name
alachlor	Lasso, MicroTech, Partner, Crop Star
alachlor + atrazine	Bullet, Lariat
atrazine	AAtrex
bromoxynil	Buctril
butylate	Sutan, Genate
butylate + atrazine	Sutazine
chlorimuron	Classic
chlorimuron + metribuzin	Canopy, Preview
chlorsulfuron	Glean, Telar
clethodium	Select
clopyralid	Transline, Lontrel, Reclaim, Stinger, Curtail
cyanazine	Bladex
cyanazine + atrazine	Extrazine II
dicamba	Banvel
discamba + atrazine	Marksman
diclofop	Hoelon, Illoxan
diuron	Karmex, Direx
ethalfluralin	Sonalan, Curbit
fenoxaprop-p-ethyl	Bugle
fluazifop-P	Fusilade 2000
fluometuron	Catoran, Meturon
glyphosate	Roundup, Accord, Shackle, Polado L, Ranger, Militia, Rodeo
glyphosate + 2,4-D	Landmaster, Forge
glyphosate + dicamba	Fallow Master, Kansel, Phenaban, Bantrol
imazethapyr	Pursuit
MCPA	Rhomene, Rhonox, KVK
metolachlor	Dual, Pennant, Medal
metolachlor + atrazine	Bicep
metribuzin	Sencor, Lexone
metsulfuron	Ally, Escort
nicosulfuron	Accent
paraquat	Gramoxone, Cyclone
pendimethalin	Prowl, Stomp, Pentagon
picloram	Tordon
primisulfuron	Beacon
prometryn	Caparol, Gowen, Prometryne Cotton-Pro
quizalofop-P-ethyl	Assure II
sethoxydim	Poast, Poast Plus
simazine	Princep, Sim-Trol
sulfonylureas	*chlorimuron, chlorsulfuron, metsulfuron, nicosulfuron, primisulfuron, triasulfuron
triallate	Far-Go
triasulfuron	Amber
triazines	*atrazine, cyanazine, simazine
2,4-D	2,4-D, Weedone, Weed-Rhap
2,4-D amine	2,4-D amine

*These are common names, not trade names. Trade names can be found by looking under the appropriate common name.

14 Insect Control in Conservation Tillage Systems

Dean K. McBride

When asked about adoption of tillage practices that leave more crop residue on the surface, producers often cite concerns about insect pest infestations. Consequently, this review discusses the effects changing tillage practices has on insects and their management.

Tillage practices may have direct or indirect effects on soil organisms. Type of equipment, timing (fall or spring), depth, and frequency of tillage operations are variables that may have dramatic effects on insect survival. Environmental conditions interact with these variables, further complicating the situation. An insect's unique response to changes in soil temperature, soil moisture, aeration, organic matter content, and bulk density of the soil represent direct effects of these variables on an insect's survival.

Because insects are cold-blooded organisms, their development rates are closely related to temperature. Insects that spend a portion of their life cycle in the soil may develop more slowly in conservation tillage systems because crop residue on the surface moderates soil temperatures by reflecting solar radiation and slowing the evaporation of soil moisture. For instance, initial emergence of corn rootworm adults is delayed in no-till corn fields. The type of tillage system may also directly influence insect survival during the winter. Research has shown that survival of corn rootworm eggs during the winter is greater in no-till systems than in more conventional systems, especially if snow cover is less than average and temperatures remain very cold for an extended period of time.

Conservation tillage systems may also have direct effects on other components in the ecosystem—components that will, in turn, influence insect populations. Examples of indirect effects of tillage on pest insect survival and development include changes in weed densities and changes in populations of beneficial (predators and parasitoids) or competitor insects in response to a particular tillage practice. These indirect effects associated with certain tillage systems might affect (positively or negatively) the density of a population of a particular insect pest. Poor weed management practices in some tillage systems have been responsible for increasing the densities of certain insect populations. Increases in the incidence of black cutworm and stalk borer damage in some no-till systems are often associated with poor weed management practices. On the other hand, some weeds attract predators and parasitoids, thereby increasing the likelihood that natural control will suppress some insect pest populations.

If reduced-tillage practices, cover crops, and crop rotations are used, agricultural systems tend to become more diversified. As a consequence the interactions of arthropods (insects and their relatives) and plant life that comprise these systems change. Some scientists have argued that pest problems could be decreased by increasing the diversity of crops or other types of plants in a cultivated area. Increased diversity of species should add stability to agricultural systems and reduce the likelihood of pest outbreaks. However, the generalization that crop diversity alone reduces pest problems does not hold true for many environment-pest situations, and pests must be evaluated on a case-by-case basis.

A study published in 1985 summarized the findings of 228 published investigations concerning the response of insect pest (herbivore or plant-eating insects) and predator populations to increased diversification of agroecosystems. Of the 79 predator species examined, 48 percent (38 species) had significantly higher populations in diverse agricultural systems, 14 percent (11 species) had significantly higher populations in monoculture systems, 13 percent (10 species) showed no significant difference in population levels between diversified and monoculture systems, and 25 percent (20 species) had a variable response to diversification.

The use of conservation-tillage practices, cover crops, and nontraditional crop rotation schemes will have impacts on insect management programs. However, whether we will be able to generalize about the effects of these cropping practices on insects and whether we will be able to use our information for the design of pest management programs are important questions we must answer first.

Although insect problems and insect management practices may be affected by reduced tillage, concern about insect problems should not prevent a farmer from adopting conservation-tillage practices. With few exceptions, effective management guidelines and tactics are available to control insect pest outbreaks, regardless of the tillage system used. In fact extension entomologists throughout the northern Plains region seldom alter insect management recommendations for different tillage systems.

For the farmer using conservation tillage, it is helpful to understand the biology, behavior, and habitat requirements of key pest species before trying to predict the impact that conservation tillage has on the abundance and survival of the pests. In addition a working knowledge of the impact of conservation tillage on natural enemies (predators and parasitoids) and insecticide application is also important.

The sections that follow discuss some of the pests of wheat and sunflower and their destructive potential, life cycle, and stages in which they are vulnerable to destruction by tillage. Also, alternative control approaches are given.

Wheat

Grasshoppers

Historically, the grasshopper has been the most destructive crop pest in the northern Great Plains. Wheat can be severely damaged in margins next to hatching beds as the young nymphs move into emerging crops. Later season damage occurs as adults migrate from barren areas into maturing crops. Stand establishment of winter wheat is severely affected as adult grasshoppers migrate into lush green fall stands. Weedy fallow fields or late-summer emergence of volunteer grains in a field can draw large numbers of egg-laying grasshoppers that will contribute to next year's problem. Climatic factors such as temperature, rainfall, and snowfall play a major role in determining the severity of a grasshopper outbreak. A long, warm fall favors grasshopper population buildup by providing ample time for egg-laying. A warm, dry spring discourages grasshopper parasites and diseases, accounting for a high survival rate for nymphs. A hot, dry summer ensures that grasshoppers will be active and hungry. A hot, dry summer also dries rangeland, forcing grasshoppers to move in search of food and moisture.

All of the economically important species of grasshoppers in the northern Great Plains have a single generation per year and begin their annual life cycle in late summer or early fall as eggs. Female grasshoppers deposit egg pods in undisturbed soil in the late summer to early fall. Incubation and development begins in the fall during warm, sunny days and ceases as winter sets in. Incubation resumes in the spring as soil temperatures increase. Hatching begins in May and continues into June. Newly hatched grasshopper nymphs resemble adult grasshoppers in appearance except for their size and lack of wings. Young hoppers begin feeding immediately in hatching sites and pass through five nymphal stages before reaching the adult stage in July and August. Grasshopper nymphs have little mobility because they cannot fly, and therefore their damage is confined to areas in the vicinity of hatching sites. Once grasshoppers molt into adults, they can fly several miles in search of a suitable site for feeding and egg laying. After reaching adulthood, grasshoppers mate and females will begin to deposit eggs. Oviposition lasts for several weeks, and each female can produce up to 250 eggs.

Conventional tillage, normally practiced in small-grain production, is destructive to grasshopper egg pods. The greater the soil disturbance, the greater the egg mortality. In addition to direct pod destruction, some grasshopper species do not oviposit in disturbed soil. Hopper eggs that survive tillage and hatch to nymphs in fallowed areas often starve before finding green vegetation.

Grasshopper survival in fields with considerable crop residue is enhanced by a number of factors. With minimal soil disturbance, egg pods are protected from soil erosion that could either bury or expose them. Stubble will catch snow that will act as insulation to protect eggs pods and increase survival during overwintering.

Regardless of the tillage system used, if fall volunteer wheat or weed growth is not controlled in a field, the field will be an extremely attractive egg-laying site for female grasshoppers and will draw grasshoppers from considerable distances. These factors can all add to a grasshopper problem in next season's crop.

Grasshopper management. The first step to grasshopper control is weed and volunteer grain control through August and September. This step reduces overall supply of food and the attractiveness of an area to egg-laying female grasshoppers. If winter wheat is to be planted, the producer should consider using a granular systemic insecticide at planting in the margins of the newly planted crop. In spring wheat, early planting allows for plant stand establishment before grasshoppers hatch. Nymphal populations should be monitored as soon as hatching begins, and controls provided as needed. Field scouting stations should extend well out into fields, especially if there was green vegetation in the field and along boundaries in the previous fall.

Grasshopper populations are measured by the number of grasshoppers per square yard. However, for the inexperienced person, it is generally easier to count the grasshoppers that jump from square-foot areas. When using the square-foot method, 18 consecutive counts in 18 different square-foot areas should be made in a field. The total number of grasshoppers observed from each of the 18 square-foot areas should be added, and the sum should be divided by two. This procedure will give the number of grasshoppers per square yard.

After the field has been surveyed at several locations, the field can be given an infestation rating based on the number of grasshoppers per square yard (table 10).

Wireworms

Wireworms can be troublesome in small grains grown anywhere in the northern Great Plains. These insects damage the seedling crop and can cause considerable stand loss in affected areas of fields. The larvae of wireworms feed on the germinating seed or the roots of the seedling plant. Initially they cause stunting, and with continued feeding they cause the eventual death of the plant. Once the stand is established, they may continue to prune roots and can reduce plant vigor. Infestations usually occur as spot problems in a field and are often most troublesome in sandy soils. Some species of wireworms spend several years in the larval stage; therefore, if a field has a problem with these wireworms one season, the field will likely have a problem the following season.

There are a number of different species of wireworms that affect wheat, but only the larval stage causes plant damage. The adult stage is called a click beetle and is present during the summer months. After mating, female click beetles lay their eggs on the soil under thatch or litter, and many species show a preference for dense, weedy vegetation, particularly grasses. The eggs hatch and the young larvae burrow into the soil where they will feed on germinating seeds, roots, and belowground stems for 1–8 yr depending on the species. Upon completion of their larval development, they pupate in the soil in the fall to emerge the following summer.

Research at Purdue University investigated the effects of different tillage programs on a number of different insects associated with corn and soybeans. These studies showed that fall moldboard plowing had either no effect on wireworm damage or slightly reduced it. Spring plowing had no effect on wireworm damage. No-till row crops planted into sod showed increased wireworm damage. The increased damage to these row crops was believed to be due to their moving from a nearby chemically-burned-down sod to the row crops to find food.

Further studies on the effect of tillage on wireworm populations in small grains would give us a better understanding of how soil disturbance affects wireworm damage. This would be most useful in areas where the annual wireworm (that is, the species for which the larval stage is less than 1 yr) causes damage to grain.

Wireworm management. There is no post emergence rescue treatment for wireworms in small grain. Planting time and insecticide seed treatments are the only controls for wireworms. Thus, it is essential to know whether wireworms are a problem in a field prior to planting. If a field has a wireworm history or wireworms are suspected to be a problem, the field should be surveyed for wireworms.

Wireworm monitoring should be conducted in the spring approximately 2 wk prior to planting. The purpose of the monitoring is to help decide whether an insecticide seed treatment should be used. The sampling technique involves taking approximately 20–40 well-spaced samples per 40 acres of land. Each sample should be about 1 ft^2 of soil taken to a depth of 4–6 inches. Each sample should be spaced out on a piece of burlap or tarp, and the number of wireworms counted. The results can be evaluated as follows:

Number of wireworms in 20–40 samples	Grain crops that can be grown safely
0–5	All crops, including potatoes
5–8	All crops, except potatoes
9–15	Small grains, except corn
20 or more	None

When wireworm populations exceed the upper limit, the fields should be fallowed or planted to alfalfa or sweetclover, which appear to tolerate the wireworms and reduce their populations.

Wheat Stem Sawfly

Historically the wheat stem sawfly has caused considerable crop loss to wheat in the northern Great Plains. This native insect originally inhabited stems of a wide variety of native grasses in western North America. Sawfly larvae reduce yields by girdling the inside of the wheat stem above the soil level, causing the stem to fall or lodge. Sawflies were first recognized as a pest of wheat in the late 1800's, and the problem continued to increase until the 1940's. Host-plant resistance to sawflies was recognized in wheat, and the first sawfly-resistant variety 'Rescue' was released in 1946. Fall tillage and the development of host-plant resistance have been the two major approaches used to manage sawfly populations since then.

Host-plant resistance of wheat depends upon the solidness of the lower three internodes of the stem. All internodes of the susceptible wheats are hollow. Solid internodes cause a high mortality of later instar larvae in August. Weather also affects host-plant resistance. When considerable cloudiness occurs early in the growing season, stem solidness is reduced, resulting in increased susceptibility to sawfly infestation.

The life cycle of this insect is summarized as follows: The adult wheat stem sawfly deposits its eggs inside the stems of the host plants. Each female lays only one egg per stem, but several females may oviposit in the same stem. The larvae tunnel inside the stem and destroy each other until only one remains. Light penetrating the ripening stem causes the surviving larva to move down to the base of the stem until it reaches ground level. Here it cuts the stem and places a plug of frass (solid larval insect excrement) in the exposed end of the stub. After plugging the stem, the larva forms a cocoon in the stub (singular of stubble) and remains there from late August to the following June. In early May the larva pupates inside its cocoon after undergoing an obligatory developmental phase that is completed after a minimum of 90 days at temperatures above 10 °C (50 °F). In June the adult chews a hole through the cocoon and plug in the stub and emerges to infest the new crop. The adult is a weak flier and generally migrates to the nearest available host plants.

Research in Saskatchewan has revealed that conventional fall tillage can account for 60–90 percent of the mortality of the overwintering larvae. It has also been reported that spring cultivation with various implements caused an average mortality of 24.2 percent compared to 8.1 percent mortality in undisturbed stubble. The one-way disc was the most effective implement tested, leaving 27.5 percent of the stubs exposed on the soil surface. Unpublished research trials in Froid, MT, in 1983 showed that almost twice as many wheat stem sawfly survived the winter in no-till plots compared to in spring-disked plots. Thus, there is a real concern with the buildup of wheat stem sawfly population in no-till systems. When tillage is not used to reduce overwintering populations, more emphasis is placed on host-plant resistance.

Wheat stem sawfly management in no-till. The first step in insect pest management is to survey populations to see whether they are high enough to be of concern. Surveys of wheat stem sawfly should be conducted at the conclusion of harvest. The survey should be a count of the overwintering larval population. At least two samples per field should be examined. One sample should be taken near the long margin of the field within the first few drill rows, and the other near the center of the field. At each location 50 consecutive wheat stems of a drill row should be examined for stubs cut off by the sawfly larvae. The total number of these sawfly stubs found in the two samples should be recorded as the percentage of infestation for the field.

Infected fields should be placed into one of four infestation ratings based on the percentage of stems cut. These ratings are as follows:

Infestation rating	Percentage of stems infested
Light	0–5
Moderate	6–24
Heavy	25–39
Severe	40–100

If sawfly populations are at the moderate rating or higher, management practices that will help control this pest should be implemented. There is no practical chemical control for wheat stem sawfly. Management of the wheat stem sawfly should include the use of resistant varieties, delayed planting of susceptible varieties, early harvest, and rotations that include nonsusceptible crops.

Hard red spring wheat varieties that have demonstrated resistance are 'Cutless,' 'Fortuna,' 'Glenman,' 'Lancer,' 'Leader,' 'Lew,' and 'Tioga.' If a susceptible variety is to be planted, delay of planting will reduce sawfly damage. In most cases, however, this is not practical. For a producer to avoid an infestation, the seeding date must be delayed until after May 20 in North Dakota and Montana, which is beyond the time when a normal yield may be expected. The yield reduction due to delayed planting could be greater than the actual loss due to sawflies. Sometimes weather conditions delay planting until May 20 or so; when this happens, one advantage to be kept in mind is that the crop will escape sawfly damage.

Early harvest is also helpful in reducing sawfly losses. In August sawfly larvae are actively engaged in cutting wheat stems. The longer harvest is delayed, the greater the number of stems cut.

Crop rotation can be helpful in reducing populations of sawflies. Crops such as oats, flax, mustard, sunflower, legumes, and safflower are not susceptible to damage by sawflies. Barley, durum wheats, and winter rye are hosts but allow only a small number of larvae to survive. In most seasons winter wheat will mature before the sawfly has time to complete its development. The use of resistant varieties and crop rotation reduces sawfly populations in the northern Plains area. Early harvest can reduce damage in some years.

Hessian Fly

Adult Hessian flies usually emerge in April from overwintered puparia at the base of wheat plants. The females deposit eggs the previous fall on the grooves of the upper surface of wheat leaves. After the eggs hatch, the larvae immediately move to a position between the leaf sheath and stem, sometimes just above a joint but usually below ground level. After the larvae finish feeding, they pupate in a caselike puparium wrapped within a leaf sheath next to the stem. Development of this spring generation can occur in either winter or spring wheat.

A second generation of adults emerges from wheat stubble in late summer or early fall. In midsummer females deposit eggs on the leaves of young winter wheat plants or volunteer wheat in the late summer. Larvae mature to the pupal stage by midautumn and overwinter as pupae, from which next spring's adults will come.

Hessian fly populations have a greater chance to carry over in fields where volunteer wheat is not controlled. Hessian flies from undisturbed stubble can move to new wheat that is planted in the spring. Flies that infest volunteer wheat in the late summer and early fall overwinter in the volunteer plants and can move to other fields in the spring (regardless of those fields' fall planting dates). As a consequence, destruction of volunteer wheat and planting after fly-free dates are extremely important. If wheat is seeded on or after the fly-free date for a specific location, Hessian fly adults have emerged and died before the crop is up. Farmers should destroy volunteer wheat and wheat planted in setaside acres by mid-September to prevent Hessian fly females from finding hosts. This procedure will help reduce the overwintering population that might disperse to nearby fields in the spring.

There are a number of winter wheat varieties with resistance to Hessian fly. Local State Experiment Stations can generally provide the latest information on resistant varieties. There are two semidwarf hard red spring wheat varieties that have resistance to Hessian fly. They are 'Guard' and

'Shield,' both of which were developed and released by South Dakota State University. While 'Shield' yields better than 'Guard,' 'Shield' is reported to be prone to shattering.

Wheat Curl Mite

The wheat curl mite is not an insect; this mite is in the arthropod class arachnid with the spiders, ticks, and scorpions. The wheat curl mite is potentially dangerous to wheat production, not as a result of its feeding damage but because it is the vector of wheat streak mosaic virus (WSM). This disease has principally been a problem in the traditional winter wheat growing areas, but as winter wheat production expands, so does the occurrence of the disease.

The adult mite is less than one one-hundredth of an inch long and is barely visible to the naked eye. Thus monitoring this mite population is not practical. The wheat curl mite overwinters in a dormant state under the leaf sheath of winter wheat or volunteer wheat. When the first flush of new wheat growth occurs in the spring, the mite becomes active. Mite numbers increase as the plant grows; they move upward on the plant to feed on the newest, most succulent tissues. The life cycle can be completed in 7–10 days under ideal conditions. In 60 days a single mite can produce millions of offspring. They reproduce most rapidly at 70–80 °F, very slowly at 48 °F, and do not develop at temperatures less than 32 °F. Wheat curl mites die very quickly when deprived of green plant material. In laboratory studies at Kansas State University, curl mites live less than 8 hr without food at 75 °F and only 1 to 2 days at 36 °F.

As winter wheat matures in late June to early July and begins to dry, it is no longer a suitable host for the mite. At this time the mites move to the outer surfaces of the head and upper leaves of the wheat plant where they stand upright attached only by their anal sucker. In this position they are exposed to wind currents that pick them up and randomly disperse them. The movement of mites in the airstream is completely at random. They have no wings to control their flight. If by chance they are carried to a suitable host, they will begin reproducing again. As winter wheat matures, spring wheat is in earlier stages of development and is a suitable host for colonization. Mites feeding on winter wheat plants infected with wheat streak mosaic virus will carry the disease. As spring wheat matures and dries down, wheat curl mites again move out on the plant and are dispersed to volunteer wheat and early planted winter wheat. Thus winter wheat and volunteer wheat serve as a bridge to carry the vector and disease from one season to the next.

Other plants besides volunteer wheat and winter wheat can serve as overwintering hosts for both the disease and the mite. Researchers at South Dakota State University studied the role of native and weed grasses in the spread of WSM. The study showed that it is unlikely that WSM epidemics could come from native grasses because all the native grasses tested were unsuitable hosts to either the virus or the mite. However, imported weed grasses such as green foxtail were found to serve as a late-summer reservoir for the disease and the mites which can then be transported to winter wheat. Even though mites that develop on green foxtail will not survive on wheat, they were found to feed long enough to infect winter wheat with WSM. The movement of the disease within winter wheat stands was found to be due to wheat-adapted mites that are already present in the crop. Nebraska studies reported other grass hosts of the mite and disease to be corn, jointed goatgrass, Canada wild rye, sandbur, smooth crabgrass, and grama. All of these grasses could theoretically be important in WSM epidemics but this is rarely the case. Instead these grasses serve as long-term reservoirs for the virus and mite, but apparently the population of these grasses does not build up high enough to be the source of major epidemics. Severe outbreaks are often traceable to volunteer wheat.

There is no cure for WSM disease in wheat. Controls must be directed at the mite vector. Controlling the wheat curl mite involves destruction of intermediate host plants that are required to carry the mites from spring wheat to winter wheat in the late summer. A 2-wk period without available host plants is long enough to kill wheat curl mites. The destruction of intermediate hosts for the mite may be done with either conventional tillage or chemical burn-down.

Management of wheat curl mites. If WSM is a problem in your area, control measures for this disease should be incorporated into your program. North Dakota State University points out the following control strategies for WSM disease in North Dakota no-till. Volunteer wheat and grassy weeds should be destroyed with a chemical herbicide at least 2 wk before planting winter wheat into a fallow field. Planting winter wheat after September 10 reduces the chances of infection, since mite activity decreases as temperatures cool.

'Butte,' 'Oslo,' and 'PR 2369' varieties of spring wheat show good tolerance to WSM. The Durum variety 'Ward' shows some degree of tolerance. All winter wheat varieties with good winter hardiness for North Dakota are susceptible to WSM.

Additional research is needed in the area of chemical fallow herbicides that can burn down volunteer wheat in fallow fields in the late summer. A cool, wet August can cause a decrease in activity of the burndown herbicide, thus delaying the planting of winter wheat. Alternative chemicals and tank-mix additives should be researched to improve burndown performance during unfavorable climatic conditions. Work should continue on screening wheat cultivars for resistance or tolerance to WSM. When resistance is identified it should be incorporated into new breeding lines when possible.

Sunflower

Most of the insect species attacking sunflower (both oil and confection varieties) in the northern Great Plains are host specific to the crop. Consequently, rotation from sunflower to small grains or another nonsunflower crop can help reduce insect infestation and damage. However, if sunflower is planted in close proximity to fields where sunflower was grown the previous year, infestation can still occur if overwintering insects move from the neighboring field into the new field. The primary benefits of insect species control resulting from crop rotation will probably be in the reduction of several sunflower diseases. Tillage appears to have minimal, if any, impact on several major sunflower insects such as sunflower seed weevils, sunflower stem weevils, and banded sunflower moth. Although spotted sunflower stem weevil larvae do overwinter at the base of sunflower stalks, research has indicated that tillage is mostly ineffective in increasing overwintering mortality of the larvae because they are protected within the woody (basal) portion of the stalk. However, delaying planting (to late May or early June) can be successful in lowering weevil densities in sunflower stalks and reducing damage by this insect.

Sunflower seed weevil larvae and banded sunflower moth larvae overwinter at depths of several inches in the soil. Consequently, it is not likely that commonly used tillage methods will have anything but minimal impact on these insects.

In summary the most effective means of managing sunflower insects in the northern Great Plains is through the use of diverse crop rotation and registered insecticides. Insecticides should be applied when field monitoring suggests that economic thresholds have been reached and at a time in the development of the crop when such treatments will provide good control.

Beneficial Insects

Much of the research regarding the effects of cultural practices on insects has focused on pest population fluctuations. Many research investigations concerning cover crops, crop rotation, and tillage systems have ignored beneficial and nontarget insects, key components in crop production systems.

In general reducing tillage (reducing disturbance of residues and the top few inches of the soil profile) favors the survival of ground beetles, rove beetles, spiders, and ants. These groups of arthropods contain a number of generalist predators that feed on other insects. Reducing tillage sometimes allows some increase in weed presence, at least during some portions of the season. The presence of flowering weeds provides nectar and pollen for parasitic wasps. Because the conditions that favor survival and reproduction of beneficial species also favor certain pests, increases in numbers of predators and parasitoids may or may not lead to a reduction in overall pest numbers or damage.

Summary

Concern about insect pests should not prevent growers from adopting conservation tillage practices. Although the potential for insect problems is slightly greater in reduced-tillage and no-till crops than it is in conventional-till fields, adequate management guidelines and control tactics are generally available for reduced- and no-till systems. An efficient and economic insect management program must include:

- An understanding of the relationship between crop rotation and insect biology
- Effective weed control
- Regular monitoring or scouting programs in each field, including detailed records and field histories
- An understanding of current economic thresholds and treatment guidelines
- Timely insecticide applications when necessary
- Proper selection and placement of soil insecticides
- Consideration of insecticide seed treatments.

Other Sources

The following extension publications, available through local county extension offices or the North Dakota State University distribution center, provide additional information on the insects discussed in this chapter and their control:

Cooperative Extension Service, North Dakota State University publications:

	Publication number
Wireworm Control	E–188
Grasshopper Biology and Management	E–272
Wheat Stem Insect Pests and Management Practices	E–680
Sunflower Seed Weevils	E–817
Sunflower Stem Weevils	E–821
Banded Sunflower Moth	E–823
Insect Pest Management for Sunflower	EB No. 28

Table 10. Grasshopper infestation ratings based on the population level of nymphs (young hoppers) and adults

	Nymphs per square yard		Adults per square yard	
Infestation	**Margin**	**Field**	**Margin**	**Field**
Light	25–35	15–23	10–20	3–7
Threatening*	50–75	30–45	21–40	8–14
Severe	100–150	60–90	41–80	15–28
Very severe	200+	120	80	28+

*Control is advised when the infestation reaches the threatening category.

15 Crop Disease Control in Conservation Tillage Cropping Systems

Marcia McMullen and Art Lamey

Environmental Changes from Increased Residues

Crop residue covering at least 30 percent of the soil surface provides several environmental changes in the soil and on the soil surface, and these changes may affect the kinds and levels of crop diseases that occur.

Reduced tillage allows such residue cover to persist and generally results in increased soil moisture, decreased early season soil temperature, and a potential increase in weeds and volunteers. These factors, in turn, affect the growth and survival of many important field crop disease organisms that survive in soil, crop residue, or weed hosts. A few diseases, such as leaf and stem rusts of wheat, are not directly affected by tillage because their survival and spread occurs on living plants in southern Plains states and is independent of survival in soil or residue.

Standing crop stubble or surface residue does not decompose as rapidly as residue incorporated with tillage. Decay organisms need direct contact with residue to inoculate it and need moisture to be active. These conditions facilitate rapid decay of the residue when it is incorporated. Disease organisms that have colonized the crop residue may survive better when that residue is left standing or is not incorporated. Disease organisms such as the fungus that causes tan spot of wheat have been shown to survive up to 4 yr on surface wheat residue. Leaf disease organisms, such as the tan spot fungus, are favorably positioned at the soil surface for release of their spores—a release that wouldn't occur if the residue was buried.

The increased soil moisture and decreased soil temperatures associated with reduced tillage favor certain disease organisms, such as the fungus that causes take-all root rot of wheat, which thrives under wet, cool soil conditions. In contrast the fungus that causes common root rot of wheat, thrives under warm, dry soil conditions, and this disease has been shown to be less severe under conservation tillage.

Weeds and volunteer plants that are more common with conservation tillage practices may host certain cereal and row crop insects and disease organisms. For example, the wheat curl mite discussed in chapter 14 carries the wheat streak mosaic virus from volunteer wheat or grassy weed hosts to the wheat crop. Destruction of these weeds and volunteers with herbicides prior to planting of the new wheat crop is the primary method of control of wheat streak mosaic.

The remainder of this chapter summarizes information on the major crop diseases affected by tillage in the northern Great Plains and provides management strategies for these diseases.

Conservation Tillage and Disease Management Strategies

A number of strategies may be followed to successfully manage crop diseases in the absence of tillage. Seed treatment with fungicides, weed control, and use of crop rotation, chemical fallow, adapted disease-resistant varieties, and high-quality seeds can all help in the battle against crop diseases. Integration of several of these strategies often is necessary to control a particular disease.

Crop rotation, or choice of crop sequence, is the most effective means of controlling crop diseases under conservation tillage. Broadleaf crops, such as soybeans, sunflowers, and flax, do not have diseases in common with the cereal crops, and so alternation between a broadleaf crop and a cereal is the best rotation choice. Continuous cropping of the same crop, for example, planting wheat into wheat stubble year after year, is more likely to cause disease problems. Chemical fallow between crops may reduce disease levels if weeds and volunteers are controlled.

Varieties of a crop may differ in their resistance or tolerance to diseases affected by tillage practices. For example, certain hard red spring wheat varieties showed decreased leaf disease severity while other varieties showed decreased head scab severity during the leaf disease and head scab epidemics in North Dakota in 1993. Wheat varieties in other areas and other years have also shown tolerance to these diseases. Only these varieties that have been tested in a region and shown to perform well under disease pressure should be chosen. Information on current varieties and their disease resistance should be obtained from local experiment station and extension offices.

The seedbed of a conservation tillage field is likely to be wetter and colder in the spring than that of a conventionally tilled field. Seed may not germinate as quickly under these conditions. A high-quality seed with good germination and vigor is desired for good stands and emergence. Seed pretreatment with fungicides may improve germination and emergence under no-till systems.

Destruction of disease-hosting volunteers and weeds in the field and along the field margins prior to planting will reduce disease potential. This is especially true for management of wheat streak mosaic virus. Herbicide applications and tillage are effective means for control of weeds and volunteers.

Foliar fungicides may be used to control residue-born leaf diseases of small grains, such as tan spot of wheat, and leaf diseases of row crops, such as dry bean rust. For example, when wheat is planted into wheat stubble, the risk of tan spot infection is high. Foliar fungicides should be planned as part of the operation costs but, since their costs are appreciable, should not be used if the weather doesn't favor disease development or if crop yield potential is low.

Cereal Diseases

Wheat

Tan spot. Tan spot is a leaf disease of winter wheat, spring wheat, and durum and is caused by a fungus that survives in wheat residue. The risk of tan spot infection greatly increases when wheat is planted into wheat stubble because the fungus readily overwinters on unincorporated wheat residue. Spores are released from fruiting bodies on the straw during wet weather in the spring and summer. Tan spot is favored by extended wet weather and moderate temperatures. If dry conditions prevail, tan spot is less common, even when wheat is planted into wheat stubble.

Tan spot appears on wheat leaves as small, tan oval spots with dark brown centers and a yellow halo around the spots. The spots may increase in size, join, and eventually cover the leaf area. Under severe infections, yield losses of up to 40 percent are possible.

Management of tan spot under conservation tillage may be achieved with crop rotation, resistant varieties, and foliar fungicides. Crop rotations should include at least one broadleaf crop or barley or oats. Barley and oats are generally not hosts to tan spot fungus.

Other leaf diseases of wheat. Septoria leaf diseases and *Septoria* glume blotch are caused by fungi that survive in wheat residue. These diseases are favored by warm, wet weather, and the risk of them infecting wheat is higher when wheat is planted into infected wheat residue. *Septoria* diseases are managed with crop rotation, resistant varieties, and foliar fungicides. Bacterial leaf diseases also survive in wheat residue. Crop rotation will reduce the risk of bacterial leaf diseases, but foliar fungicides do not protect against bacterial infections.

Head scab. Head scab of wheat is caused by a fungus that survives in cereal residue, including wheat, barley, and corn residues. In corn the fungus causes a disease called corn stalk rot. Head scab of wheat is favored by warm, highly humid, wet weather during the flowering stage of the wheat crop. The fungus invades the flower and subsequently causes partially bleached heads and shriveled, lightweight kernels. In areas where rainy weather is likely to occur at flowering and where this disease is common, wheat should not be planted into wheat or corn stubble. Corn residue does not decompose rapidly, and the head scab fungus survives for at least 3 yr in this residue. Crop rotation is the primary effective means for management of wheat scab. Although all currently grown wheat and barley varieties are susceptible to head scab, recent scab epidemics indicate that some wheat varieties show more tolerance to infection than others and have better yields and quality during periods of severe scab infection. Consult your state extension service for performance of varieties in your area.

Cephalosporium stripe. Cephalosporium stripe is caused by a fungus that survives up to 5 yr in wheat residue in the top 3 inches of soil. This disease is most severe in winter wheat planted into wheat stubble and in wet, acid soils. The disease is rare in spring wheats. The fungus infects the plants through the roots and then invades the water-conducting tissues of the aboveground parts. Infected plants are dwarfed, and distinct yellow-to-brown stripes develop on the leaf and run the length of the blade. Heads of the infected plants appear white and seed is not set or is very shriveled. A 3-year rotation with nonhost crops is the best method for control. Varieties also vary in their susceptibility to this disease.

Wheat streak mosaic. Wheat streak mosaic is often the most damaging disease of winter wheat in the northern Great Plains. Infections have been severe in spring wheats and durums as well. Barley and oats also may become infected with this virus disease, but infection in these crops is much less common than in wheat.

The virus is spread from plant to plant by the tiny wheat curl mite that transmits the virus during feeding. Grassy weeds and volunteer wheat serve as hosts for the mite to feed on between summer harvest and fall emergence of winter wheat. Perennial grasses, volunteer winter wheat, and seeded winter wheat also serve as hosts for overwinter survival of the mite and virus. Infected wheat plants are stunted and the leaves have a yellow-green mosaic or yellow-green striped appearance. Plants infected at early growth stages often produce few or no heads whereas plants infected later in their growth have reduced seed set.

Management of this disease requires successful control of grassy weeds and volunteers several weeks prior to planting. In the absence of tillage, these weeds should be controlled with herbicides. A delayed planting of winter wheat reduces the risk of exposure to high mite populations in the fall, and an early planting of spring wheats helps reduce the risk of wheat streak. Further recommendations for control of this disease and its carrier are contained in chapter 14.

Take-all. Take-all is caused by a fungus that survives in small-grain residue. The take-all fungus that attacks wheat will also infect barley. Reduced tillage favors infection because residue on the surface is often infected and soil moisture is generally higher.

Irrigated wheat or wheat planted into wheat or barley stubble in a wet year or wet location is at high risk of infection. Plants infected with take-all are bleached or prematurely white in appearance and have very shriveled grain. Infected plants often occur in patches in the field. The best symptom for diagnosing take-all disease is the shiny, black discoloration found at the base of the stem and in the crowns and roots.

Where take-all has become a major problem, it can be controlled by cropping for several years with crops other than wheat or barley, such as alfalfa, corn, millet, sorghum, flax, and canola.

Common root rot. Common root rot is caused by a fungus that survives in the soil. The fungus attacks wheats and barley. The disease is favored by warm soils and drought stress on the plants; thus, this disease is more severe with conventional tillage than with reduced- or no-till production. Common root rot infection is characterized by brown-to-dark-brown lesions on the roots, subcrown internodes, and the crowns of infected plants. After heading, plants may turn prematurely white and have poor seed set and grain fill.

Keeping more residue on the soil reduces the level of common root rot but does not eliminate the disease. Crop rotation is the best method for management and should not include wheat or barley for several years. Varieties also vary in their susceptibility to this disease. Two seed treatment products, imazalil and triadimenol, are registered for suppression of this disease. In this chapter generic names are used for pesticides. Trade names under which these pesticides are commonly marketed are given in table 11.

Barley

Leaf spot diseases. Net blotch, spot blotch, *Septoria* leaf blotch, and powdery mildew are fungal leaf diseases of barley that survive in barley residue. Several bacteria that may infect the barley leaves also survive in barley residue. The risk of these diseases is high if barley is planted into barley residue and wet weather occurs. Net blotch is characterized by dark-brown-to-black lesions running parallel and perpendicular to the leaf veins. The main symptom of spot blotch is black oval spots on the leaves. *Septoria* leaf blotch is characterized by tan spots or blotches with tiny, black round fruiting bodies within these spots. Bacterial leaf diseases are characterized by water-soaked leaves, followed by brown streaks running parallel to the leaf veins. These diseases also may infect the heads and kernels if wet weather prevails at grain fill. Powdery mildew is characterized by white, fuzzy superficial growth of the fungus on the leaf blade.

Management of these leaf diseases is through crop rotation, resistant varieties, and foliar fungicides. Fungicides should be used only when yields and environmental conditions indicate that an economic return from the fungicide is likely. Foliar fungicides will not control bacterial leaf blight.

Take-all. See information in wheat section.

Common root rot. See information in wheat section.

Wheat streak mosaic. See information in wheat section.

Oats

Leaf diseases. Organisms that cause leaf diseases, such as *Septoria* leaf blotch or bacterial stripe blight, survive in oat residue for several years. Oats planted into oat stubble are at high risk for these diseases if wet weather prevails. Crop rotation with nonhost crops is recommended for control of leaf diseases.

***Fusarium* foot rot.** The fungus that causes this root disease survives in the soil and in wheat, barley, and oat residue. In the northern Great Plains, this disease generally is more common on oats than on wheat and barley. Crop rotation with a nonhost crop is recommended.

Take-all. The take-all fungus infects oats under conditions similar to those favoring take-all in wheat and barley. A separate species of the take-all fungus attacks oats but not wheat or barley. Crop rotation with a broadleaf crop is recommended where fields are infected with take-all fungus.

Sorghum

Bacterial and fungal leaf diseases. Bacterial and fungal leaf diseases are common on sorghum in wet growing seasons. The causal bacteria and fungi survive in infected sorghum residue and most are specific to sorghum. Sorghum should be rotated with nonsusceptible crops to manage these diseases.

***Fusarium* root and stalk rot.** The *Fusarium* fungi that cause root and stalk rot survive in corn and sorghum residue. This disease is most severe when cool, wet weather is followed by hot, dry weather as plants near maturity. Root and stalk rot has been shown to be less severe in reduced tillage than in conventional tillage. In semiarid locations, sorghum planted into a 3-yr, reduced-tillage rotation system (called eco-fallow) had reduced stalk rot and an improved yield compared to conventional tillage. This rotation (winter wheat-sorghum-fallow) also controlled weeds and conserved soil moisture, reducing the stress on the sorghum so that it was more able to resist the root and stalk rot.

Diseases of Broadleafed Crops

The *Sclerotinia* fungus attacks many broad-leaved crops. Sunflower, dry edible beans, and canola are highly susceptible. Other susceptible crops include lentils, safflower, potatoes, and soybeans. The *Sclerotinia* fungus produces a mushy brown rot that later becomes bleached. This rot usually occurs on the stems or stalks of infected plants. Hard black bodies called sclerotia develop in infected plant tissues. These sclerotia survive up to 6 or more years in the soil and may germinate to infect the roots of sunflower, producing a basal stalk rot or Sclerotinia wilt.

Sclerotia on or near the surface of the soil do not survive as well as those buried by conventional tillage. However, sclerotia on or near the soil surface may germinate in wet weather, producing mushroomlike bodies that liberate airborne spores. These spores infect blossoms of susceptible crops and may lead to infections in fields previously free of *Sclerotinia*. This is of particular significance if sunflower is planted in the same field in a subsequent year.

Rhizoctonia is a soilborne fungus that causes seedling disease and root rot of several row crops. Dark spots with brick-red borders develop on roots of infected dry beans and soybeans. Infected sugarbeet roots may develop dark spots, or the entire root may develop a dry rot. Infection is favored by warm, moist soils. The disease is more likely to be severe under reduced tillage, since the soil has greater moisture and since deep plowing cannot be used to reduce disease potential by distributing the *Rhizoctonia* fungus over a larger soil mass. The same strains of the *Rhizoctonia* fungus attack dry edible beans, soybeans, and sugarbeets.

Disease management includes avoiding short rotations among susceptible crops and use of seed treatments containing terraclor to reduce early season infection from *Rhizoctonia*. In-furrow treatment with terraclor or metalaxyl may be used on dry beans if heavy disease pressure is expected.

Sunflower

Sclerotinia. Sunflower is the only crop regularly infected through the root by *Sclerotinia* . Infection and spread of *Sclerotinia* in sunflower is less dependent on favorable weather conditions than infection in other crops. Head rot may develop if wet weather occurs at heading. Sunflower fields with 10 percent of the crop infected need a 4- to 5-yr rotation to nonsusceptible crops to reduce wilt to about 5 percent.

Rust. The typical symptom of rust is dark brown pustules on the leaves and other plant parts. Yields, seed size, and oil content may be reduced as much as 20–30 percent. Rust survives on sunflower crop residue. Early season infection occurs on volunteer sunflower and wild sunflower. Hybrids generally differ in their susceptibility, but confection hybrids tend to be more susceptible than oilseed hybrids. Before 1988 many hybrids had resistance to races 1 and 2, which were the predominant rust races. By 1988 the predominant races had changed. Race 3 is now the dominant race, and race 4 is also present. Some hybrids have resistance to race 3, but no hybrid is resistant to race 4.

Rust is managed by controlling volunteer and wild sunflower prior to planting sunflower. Hybrids with resistance to race 3 should be selected if possible. Other management strategies include using crop rotation, early planting, or short-season hybrids and avoiding high levels of nitrogen fertilizer.

Dry Edible Beans

White mold. The most serious dry bean disease in the northern Plains is white mold. It is particularly severe under sprinkler irrigation and in years with high rainfall during blossoming. Airborne spores may be released from refuse of *Sclerotinia*-infected row crops on or near the soil surface. These spores may cause infection in nearby dry bean fields. Crop rotation is of relatively little value in managing white mold if dry beans are commonly grown in an area.

White mold management strategies include using widely spaced rows, planting upright varieties, planting varieties with some tolerance to white mold, and avoiding ammonium fertilizers (including urea and anhydrous ammonia), which promote white mold development. Irrigators should minimize the number of overhead irrigations at blossom time. Fewer and deeper irrigations help reduce the amount of white mold infection.

Benomyl, thiophanate-methyl, and iprodione fungicides may reduce white mold infection and increase yields substantially. A banded application at early bloom is economical and effective if yield potential is 2,000 lbs/acre or greater. Drop nozzles should be used between the rows with a third nozzle above the row.

Rust. The typical symptom of rust is tiny spots with a rusty powder and a narrow yellow border. The rust fungus survives on dry bean crop refuse. Some varieties are resistant or tolerant to rust. Although varieties differ in susceptibility, many varieties of kidney, black, and cranberry beans are resistant to rust, and some navy bean varieties are resistant. Many pinto and most great northern bean varieties are susceptible.

To manage rust producers should avoid planting next to fields that had dry beans the previous year. Once the crop is planted, field scouting should be done to determine whether rust infections are present in a field. Areas near shelter belts that tend to stay wet longer should especially be checked. Use of mancozeb or chlorothalonil fungicides can be good investments if several pustules per leaf are present before the lower pods are filled.

Sugarbeets

Cercospora leafspot. The most common foliar disease of sugarbeet in the northern Plains is cercospora leafspot. This disease can be serious in warm and humid weather, reducing root yields and percent sucrose by as much as 30 percent and increasing loss to molasses due to increased impurities. Typical symptoms are small ash-gray circular spots with dark gray borders. Spots may coalesce, killing large portions of the leaf. The leafspot pathogen survives on sugarbeet crop refuse.

Cercospora leafspot is managed by scouting for leafspot and using approved varieties, crop rotation, and fungicides. Scouting should concentrate on areas near shelterbelts where the crop stays wet longer and on areas where sugarbeets were planted the previous year. Triphenyltin-hydroxide-bearing fungicides provide excellent control. Benomyl and thiophanate-methyl provide excellent control in areas where the fungus has not developed resistance to them; they are not recommended for use in the Red River Valley of North Dakota and Minnesota. Zinc ion-maneb complex (or mancozeb) fungicide also provides control. A *Cercospora* predictive model can be used to help determine when a fungicide is needed. Many sugar companies have a separate telephone line just for the purpose of providing information on the *Cercospora* model, and they update this information daily.

Potatoes

Early blight. Early blight disease is common in the northern Plains. The early blight fungus survives on potato crop refuse. Overhead irrigation favors early blight development. The disease usually begins in midsummer and produces dark brown spots with a target pattern. Affected leaves soon turn yellow and drop off. Early blight is managed by use of crop rotation and fungicides such as zinc ion-maneb complex (or mancozeb), chlorothalonil, or triphenyltin. Varieties differ in their susceptibility. A computer program, *Potato Disease Management* (PDM), can be used to help determine when fungicides are needed for sprinkler-irrigated potatoes. Software for this model is available from the University of Wisconsin (see Cooperative Extension Service, University of Wisconsin (1986) in *Other Sources* at the end of this chapter). Some states also publicize further grower's information derived from this model.

Late blight. Late blight is favored by cool, wet weather, and is not common in the northern Plains. This disease rapidly kills large areas of leaf tissue, and entire fields may be severely damaged within a few days. The late blight fungus survives on potato crop refuse and in potato cull piles. Destruction of cull piles and use of fungicides are two methods used to manage the disease. The PDM computer program can be used to help determine when fungicides are needed for control of late blight in sprinkler-irrigated or dryland potatoes.

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Table 11. Generic and associated trade names for pesticides discussed in chapter 15 on disease control

Generic names	Trade names
benomyl	Benlate
chlorothalonil	Bravo
imazalil	Nu-Zone, Double R, FloPro IMZ
mancozeb*	Manzate 200, Dithane M-45
metalaxyl + PCNB	Ridomil PC
iprodione	Rovral
PCNB	Terraclor
thiophanate-methyl	Topsin M
triadimenol	Baytan
triphenyltin hydroxide (fentin hydroxide)	Super Tin, TPTH DuTer is a discontinued name.

*Mancozeb is an ISO and BSI common name but is not officially recognized in the United States. It is, however, widely used in the United States as a common name for zinc ion maneb complex, or a coordination product of zinc ion and manganese ethylenebisdithiocarbamate.

16 Erosion Control with Sparse Residue

J.F. Power

Factors Leading to Sparse Residue Cover

In some years only a small quantity of residue is produced by a crop. This may happen because of drought, hail, insects, or diseases or it may just be the result of the nature of the crop produced. For example, soybean loses its leaves before harvest; they decompose within a few weeks, and only the stems and branches are available for residue management. Sunflower, sugar beet, potato, corn silage, and flax also leave very small amounts of crop residues. In spring wheat-fallow systems, very little crop residue remains by the second winter of the 21-mo fallow period. In such instances great care must be taken to effectively use the crop residues that are available. Even with good conservation of the sparse residues, additional practices may be needed in order to control water and wind erosion.

Options for Reducing Erosion in Low-Residue Fields

No-Till and Reduced Tillage

The most effective option for reducing erosion in low-residue fields is generally to use no-till or greatly reduced tillage practices. This keeps those residues that are available on the soil surface where they provide maximum erosion protection and decompose more slowly. Under these conditions, however, there would probably be no significant reduction in evaporation losses during the summer, because about 2,500 lb of residue per acre are generally required to achieve significant reductions. If tillage is used for any reason, only subsurface sweeps should be considered so that residue incorporation is minimized. Herbicides used in no-till systems must be selected carefully to avoid residual effects on the next crop and to keep costs down. If no-till is practical, it is often the best choice for controlling erosion where there are few crop residues.

Cover Crops

Another option would be to provide more crop residue by planting a cover crop. For example, barley, oats, or rye might be drilled after corn silage harvest to provide ground cover. These crops can also be seeded in August after harvest in a spring wheat-fallow system. An advantage to oats or barley would be that they are killed by freezing, eliminating any cost associated with killing the cover crop. Hairy vetch is a legume that can be seeded in the fall as a winter cover crop and has the advantage of being a nitrogen fixer, thereby possibly reducing fertilizer costs. In the western Corn Belt, hairy vetch is sometimes overseeded into ridge-till corn in late August, providing ground cover and available nitrogen to the next corn crop. However, vetch may occasionally winter-kill above the 40th parallel, and this winterkill severely limits the nitrogen production, which mostly takes place in the late winter and early spring. Field pea, faba bean, lentil, and medic are other legume species that may be used for cover crops. Field pea or lentil planted in the early spring are used successfully in spring wheat-fallow systems in western Canada.

A major problem with the use of cover crops to provide ground cover for cropland in the northern Great Plains is the fact that the cover crop often depletes soil water supplies, thereby sometimes reducing yield of the grain crop that follows. This effect can be minimized, however, by proper selection of cover crop species and planting date. Unfortunately only limited research on this subject has been conducted to date, so a producer should use these practices judiciously. Another problem with fall-seeded cover crops is difficulty of establishment in years when rainfall in the late summer or fall is low. At the present time, cover crops appear to be more practical in more humid regions than in drier areas.

Vegetative Hedges and Terraces

When crops that produce few residues are a regular part of a cropping system, use of permanent or semipermanent structures should be considered. One such example would be the use of vegetative hedges, such as rows of tall stiff grass planted at intervals across the field. Hedges planted at angles of 40–90° from the prevailing wind direction provide significant reduction of wind velocity at the soil surface when the distance between the hedges is equal to approximately ten times their height. They also provide low wind velocity regions in which moving sand particles can settle and thereby minimize the primary abrasive agent that breaks additional particles loose from the soil during wind erosion. When these hedges are planned so that they also cross the draws where runoff flow concentrates, they cause the runoff water to pond and drop most of its sediment in a delta in the front of the hedge. With time, these deltas grow to where they effectively disperse concentrated flows that are the primary agents for sediment removal by water from fields.

In areas where protection is needed from both wind and water erosion, tall grass hedges can provide that protection. Rows of tall wheatgrass planted at intervals of 40–60 ft serve as an effective hedge for reducing wind movement and water runoff, and they also trap snow on the field during winter months. If properly designed, these hedges may increase water stored in winters with heavy snowfall by several inches. Using trees as field windbreaks is also effective, but when the windbreaks are closely spaced, the trees compete with the crop for soil water over a significant part of the field.

Strip cropping and terraces are other practices that can be used in fields where there are not enough crop residues to provide soil erosion control. These practices are very effective in controlling water erosion and can help control wind erosion if properly designed. Wind strip cropping with alternate wheat and fallow is very popular and effective in Montana and some other states. One problem is that orientation of strips for best wind erosion protection may often result in rows running up and down slope. Because the wheat stubble strips usually fill with snow in the winter, considerable water erosion may result in years when rapid snow melt occurs. Therefore, some compromises in design may be required.

Use of terraces, field wind breaks, and to some extent strip cropping are essentially permanent changes and may often require significant outlays of money for establishment. Some of these practices also require removing some land from crop production. If at some future time the removal of these structures is desired, appreciable cost may again be involved. In the past, government cost sharing has usually been available to help cover expenses in establishing these practices. However, one should seriously evaluate other available options before deciding on the use of these more permanent practices because of the costs involved.

Tillage as a Last Resort

Tillage can be used in emergencies when crop residues are very sparse. Tillage that brings clods to the soil surface (usually chiseling) can reduce wind erosion. This practice has often been used in the southern Great Plains. The soil clods provide areas on their lee sides where moving particles are trapped, thereby reducing the "sand blasting" that detaches and mobilizes other particles. Generally, however, emergency tillage should be viewed as a last resort because continued use will eventually result in complete loss of soil structure (no clods) and the soil would become susceptible to erosion to the depth of tillage.

Furrow diking equipment has also been used for water erosion control. In this practice small dikes are constructed every few feet in tillage furrows. However, if rainfall is sufficient to cause water flow over these dikes, serious rill erosion can occur.

Imported Crop Residue and Manure

There are several other practices that are sometimes used to aid in soil erosion control when crop residues are sparse. One is to spread manure or straw over the susceptible area. Particularly on silty soils, spreading manure after corn silage harvest followed by chiseling results in a very rough cloddy soil surface that can absorb several inches of rainfall and control wind erosion. When practiced over a period of years (especially if no disking is used), this results in a very friable soil with high infiltration rates. Manure or straw is often applied to erodible areas in fields not only to aid in erosion control but also to build up soil organic matter.

The practices discussed in this chapter are some of the more common practices used to control soil erosion in low-residue fields. No one practice is generally superior in the northern Plains because site-specific factors vary so greatly (soil type, slope, exposure, time of year, size of area, cropping system used, and so forth). Producers generally can obtain the best information and recommendations specific to their area from local sources (Soil Conservation Service, Extension Service, or others).

17 Management Options for Lands Concluding Their Tenure in the Conservation Reserve Program (CRP)

T.E. Schumacher, M.J. Lindstrom, M.L. Blecha, and A.L. Black

Most of the highly erodible lands contracted into the Conservation Reserve Program (CRP) suffered much erosion, organic matter loss, and soil structural deterioration while in cultivated crop production prior to the program. In this program the land was returned to grass, and significant improvements toward the structure and organic matter levels of the original grasslands have been achieved. If these improved lands are tilled again following the program, the organic matter level and structure resulting from the period in grass will be rapidly lost.

A critical question for managers of post-CRP land returning to crop production is how to maintain the benefits derived from 10 yr of grass. Going directly into no-till can be a cost-effective method of doing this. No-till avoids the rapid biological oxidation of organic matter that results from moldboard plowing (Reicosky and Lindstrom 1993). It also maintains the pore geometry and continuity developed under grass. Macropores extending from the soil surface to deep within the root zone are maintained, resulting in high-water-intake rates that reduce runoff and erosion. By keeping crop residue on the surface and a few millimeters of highly organic soil near the surface, no-till also reduces evaporation. This combination of increased infiltration and decreased evaporation makes more water available for crop production and groundwater recharge. The additional groundwater increases the base flow into our streams from springs and seepage faces that sustain the desirable components of our wetland ecosystems. No-till also reduces populations of annual weeds that require soil disturbance for germination.

No-till production systems must be adapted to the conditions of the region and the resources and needs of the producer. Some of the purposes of tillage include control of weeds, insects, and pathogens. When tillage is discontinued, alternative means of controlling these pests must be used. Herbicides provide cost-effective control for most weeds. Other examples of controlling pests include mowing field borders before weed seed set; using disease-free and fungicide-treated seeds; using crop rotations to break life cycles of diseases, insects, and weeds; and narrowing rows to allow earlier interception by the crop of the sunlight and nutrients that otherwise would nurture the weeds. Other chapters in this publication discuss development of successful no-till systems. The following discussion focuses on the CRP—how grass affects soil properties, the rates at which grass improves soil properties, post-CRP management options, the potential impacts of no-till after CRP, and some basic no-till guidelines.

Conservation Reserve Program

The CRP was initiated in 1985 under the Food Security Act with the intention of placing up to 45 million acres of highly erodible farm land under protective cover. Public perceptions of the economic, social, and environmental state of farming prior to the initiation of the farm program influenced this multiyear land retirement program. During this time period, farm prices were low, large crop surpluses existed, farm foreclosures were on the increase, and agricultural exports were decreasing. Lobbyists argued that these surpluses were preventing improvement of grain prices and that due to these surpluses large blocks of highly erodible land could be placed under protective unharvested grass cover. There was also public concern that current farming practices were destructive to both the soil's productive capacity and to wildlife habitat. Economists anticipated that the reduction in acres of grain would reduce grain production so that market prices would rise closer to target prices. Consequently, crop support prices would be lower per bushel and would be paid on fewer bushels. Based on these potentials for improving erosion control, farm prices, and the national budget, the CRP got underway.

Under this program USDA pays CRP participants an annual rent for 10 yr, plus half the cost of establishing a conserving land cover. To be eligible for the program, land has to be potentially highly erodible, actually eroding at an excessive level, or environmentally sensitive. A condition of this enrollment in CRP was that the farmers surrender their use of a proportional amount of their commodity crop base acreage. This subtracted base acreage is "returned" when the land is retired from the CRP.

The objectives of the CRP evolved during the program, and new procedures were developed for selecting lands proposed for the program. The new procedure used a productivity based rental rate and ranked bids based on the ratio of the environmental benefits index to the government cost of the contract. Special provisions for wetland enrollment were made during the 8th and 9th signup periods. U.S. conservation policy is moving to promote broader stewardship of all natural resources on the farm as indicated by the addition of the Wetlands Reserve Program, the Agricultural Water Quality Incentives Program, and the Environmental Easement Program.

Status of CRP

By 1993, 36.4 million acres of highly erodible and environmentally sensitive land were enrolled in the CRP. The first contracts will expire in October 1995. By October 1997 about 24 million of these acres will be released. Over half of the CRP acres are located in the 10 Great Plains States. Commodity crop base acreage was reduced by 23.3 million acres. One of the major payoffs of the CRP has been its significant improvement of wildlife habitat. This benefit has brought a major portion of the environmental groups to support CRP and proposed related programs. Average erosion reduction on CRP lands is estimated to be 19 tons/acre/yr. Of the land that went into CRP, 2.4 million acres were planted to trees. This tree-covered acreage has a good start toward producing a harvestable timber crop and will probably stay under tree cover for at least another 15 yr.

As contracts expire, producers are questioning what the future holds for grassland enrolled in the CRP program. Many of the highly erodible lands accepted in the CRP had previously suffered much erosion and structural deterioration. Organic matter contents, structures, and infiltration rates of soils in these lands have generally improved during their period in grass. However, these improvements will be rapidly lost during and immediately after tillage.

As CRP acres become eligible for release, landowners have many options, including leaving the acres in grass for hay or livestock production or establishing wildlife or recreation enterprises. Another option available to contract holders is to return all or a portion of the land back into crop production. Surveys indicate that over half of CRP contract holders plan to return their land to cropping upon contract expiration. Many of these producers lack experience in dealing with the grass and large amounts of residue accumulated after the land has been idle for 10 yr.

Effects of Grass on Soil Properties

The most important characteristics of soil structure are the size, distribution, and geometric arrangement of the pores. These properties of soil pores determine infiltration rates, internal drainage and aeration, water-holding capacity, and the portion of soil water that is available to plants. These characteristics tend to become optimized when there is a sod cover. Soils with the best aggregation for crop growth in the United States are soils that have been in grass for many years. These soils have greater amounts of organic matter, structural stability, total pore space, air-filled pore space, higher hydraulic conductivity, and higher infiltration rates than cropped soils that are conventionally tilled. Additionally soils of long-term grasslands tend to have more pores in the size range that contributes to field water-holding capacity than cropped soils. This results in improved water availability for plant growth. Earthworm channels connected to the soil surface reduce runoff and improve infiltration into the root zone. Populations of earthworms have been observed to be 6–9 times higher in established grasslands compared to cultivated soils.

Soils in long-term grass also show improved mechanical properties (for example, an increase in the moisture content at the lower plastic limit) that allow traffic and tillage under wetter conditions. Farmers of fine-textured soils tilled after a long period in grass observe that the time periods between when a soil is too wet to till and when it is too dry to till decrease each year after tillage begins. These farmers plan the timing of their tillage operations based on these observations.

Soil aggregates from North American virgin grasslands are more stable than those of cultivated lands. The differences appear to be due to a cultivation-induced loss of particulate organic matter that helps bind small aggregates into larger aggregates. Particulate organic matter consists primarily of partially decomposed residue and roots. This fraction has a higher turnover than other forms of organic matter and requires continual input into the soil. Grasses that form a sod cover are an excellent source of shoot residue and organic matter associated with continual turnover of an abundant fine root system. The superior aggregation qualities of grasslands result from ideal conditions of simultaneous formation and stabilization of macroaggregates found in the grass rhizosphere. Reduced returns of root system organic matter to the soil and rapid biological oxidation of organic matter induced by tillage appear to account for lower organic carbon and nitrogen found to a depth of 18 inches in long-term cultivated soils compared to virgin grasslands (Bauer and Black 1981).

When grasslands are cultivated, organic carbon and nitrogen decline most rapidly during the first 10 yr of cultivation and then decline more gradually depending on the cropping system and climate (Bauer and Black 1981). Soil structure deteriorates even more rapidly, with the greatest rate of destruction occurring in the first 2–3 yr after cultivation of long-term grasslands. The effects of tillage on soil properties after cultivation depend to some extent on soil type. However, all soil types examined (loamy sand to clay) exhibit degraded soil physical properties resulting from tillage. Long-term tillage in these soils resulted in reduced water availability and aeration within the root zone. Soil pores must be a certain size to hold water at suctions where it is available to crops. On a Crowley soil in Arkansas, the number of pores in the proper size range was reduced 14 percent by 12 yr of tillage (Scott and Wood 1989).

A major objective of the CRP is to protect and improve the soil surface with grass cover. The grass cover protects the soil surface from raindrop impact, traps water temporarily in surface microcatchments, and allows the development of cracks and pores that open up the surface, all of which reduces runoff and associated erosion.

Soil Improvement from CRP (Long-Term Grass)

Soil structure improves when cropped land is put back into grass. This is accounted for by the "land use residual" attributed to grass rotations in the development of cropping factors in the Universal Soil Loss Equation. Improved soil properties after grass can result in increased yields. Significant soil structural improvement has been observed in 3–5 yr. However, more time is required for restoration of soil properties to the state found in the virgin soil. Mazurak and Ramig (1962) estimated that the effects of grass in a medium-textured soil in Nebraska reached its maximum benefit after 10–12 yr. Soil aggregate distribution, stability, air permeability, and hydraulic conductivity improved with time in the grass treatments. A review by Kay (1990) of the effects of grass on the rates of improvement of soil structural stability indicates that significant improvements will continue for at least 10 yr. Improvements are likely to continue after this time period but at a slower rate.

Management of grass influences the benefits of grasses on soil properties. Haying grassland slows the rate of change in soil structure (Mazurak and Ramig 1962). If a legume such as alfalfa is used in the grass mix, haying reduces most of the benefits of alfalfa to the soil nitrogen pool (Haas et al. 1976). Although haying slows the effects of alfalfa and grass on soil structure, improvement continues as shown by increased organic matter and aggregate stability for at least 5 yr.

The degree of soil improvement from 10 yr of grass is likely to be soil and site dependent. As a general rule of thumb, the greater the amount of soil structural deterioration from past cultural practices, the more likely that grass management will effect an improvement in agronomically important soil characteristics. Rasiah and Kay (1994) found that if soils had higher levels of organic matter and other stabilizing materials at the time of grass introduction, the time required for soil structural regeneration was reduced. Soils in CRP generally fit into the category of degraded soils lower in organic matter than surrounding soils, since they were primarily allowed into the program based on their highly erodible classification. Highly eroded soils tend to have reduced productivity, degraded soil structure, lower organic matter, and a less-than-ideal environment for root growth (Lindstrom et al. 1992). Soils that tend to be less stable and have less-well-defined soil structure such as sandy loams or compacted clay soils may also benefit from the organic matter inputs of 10 yr of grass. Soils with past deterioration or less-than-ideal physical characteristics are likely to be poorly buffered from tillage-induced changes and are most likely to rapidly lose improvements derived from the CRP when tilled. The surface of these less-than-ideal soils is also more likely to seal following tillage, reducing infiltration and increasing water runoff and soil erosion. A critical question for managers of post-CRP land returned to crop production is how the advantages gained from 10 yr of grass production can be maintained or prolonged.

Although the degradation of structure of soils taken out of sod and tilled is well documented, less is known about the effects of no-till cropping on lands previously in sod. Presumably the rate of decline would not be as great for soils in a no-till practice, since reduction of, or abstinence from, tillage reduces disturbance of the structure and reduces the rate of biological oxidation of the organic matter.

Post-CRP Options

If funding could be obtained, the best approach environmentally for highly erodible CRP lands would probably be to extend the contracts. This would allow the soils in the program to continue to improve and would keep erosion under control. Another proposal is to subsidize a rotation program that involves 4 yr in grass production followed by 4 yr in grain production. Still another proposal is to lower CRP payments to keep the lands in grass but allow grazing or haying on these lands. The latter proposal has met considerable opposition by farmers who have land already in hay production and who object to subsidized hay production that would compete unfairly with their product. The soundness of their arguments has been acknowledged by administrators and legislators. Consequently, it is unlikely that haying and grazing will be allowed on lands on which CRP payments are being made except in emergencies.

Farmers who choose to use their post-CRP land for haying or grazing operations will have to pay their own way. In some parts of the country such haying and grazing operations on these lands could be economically viable if current hay prices could be sustained. However, demand for hay is declining as red meat consumption declines, local hay markets are limited, transport costs of hay are high, and major increases in hay production may occur after the CRP program is over. The reduced demand and increased supply are likely to result in depressed prices and little profit for the farmer.

Another market that may develop for dry grass is its use as a fuel for power plants. Initial results from studies funded by the Department of Energy are encouraging and indicate that prices in the range of $40–50/ton could be paid for dry hay used for this purpose. However, construction of the power plants and development of this market would take at least 10 yr, so this market will not be available to many, if any, of the farmers at the time when their land comes out of the CRP.

Before deciding what to do with their post-CRP land, individual farmers should evaluate existing and developing markets in their area. Existing commodity support payments will help protect farmers from decreasing prices for their products on the supported crops for which they have base acreage allotments. However, the long-term provisions of GATT will reduce those supports.

The following is a list of possible options for the farmer:

I. Maintain grass cover on the land.

a. Produce hay. Use management designed to avoid disturbance of nesting birds (for example, delay the first cutting until danger of disrupting nesting birds is past).

b. Graze animals on the land. Rotate grazing areas to minimize disruption of nesting birds and grass deterioration.

c. Manage the land to preserve wildlife. This could include development of fee hunting preserves, etc., and might be combined with some of the other options where provision of improved wildlife habitat is designed as part of the conservation plan.

d. Extend the CRP contract, if possible.

II. Return the land to cropping.

a. Use no-till practices, (low-disturbance systems). Plant into dead sod, and use appropriate rotation systems to manage weeds, pests, and fertility without a dramatic increase in purchased inputs. Maintain surface residue and soil structure.

b. Use a wide V-blade sweep to undercut sod. Then use no-till or minimum-till methods of planting and crop production.

c. Use a moldboard or chisel plow prior to a no-till system. After plowing disrupts and buries a major part of the initial residue, no-till will maintain residue of subsequent crops on the surface.

d. Use conventional tillage only. If the land has been designated as highly erodible, the tillage system and rotation must be modified to fit the conservation plan developed for conservation compliance.

e. Create a meadow and rotate it with crops. Plant grass, legumes, or a mixture of the two as a meadow. Rotate each field between crops and meadow to reduce average annual erosion rates.

For most of the CRP lands where contracts cannot be renewed, no-till management appears to provide the greatest potential for achieving reasonable net returns while retaining most of the soil quality improvements achieved during the CRP. The section that follows further describes how CRP lands can be cost effectively transitioned to economically and environmentally sustainable production systems (see chapter 10 also).

No-Till After CRP

Cropping practices that avoid tillage have the advantage of avoiding the rapid mineralization of carbon and nitrogen that occurs when grass or crop residues are mixed with the soil by tillage. Reicosky and Lindstrom (1993) measured successively higher rates of carbon dioxide from wheat stubble plots subjected to no-till, disking, chisel plowing, and moldboard plowing. They found that the rate of biological oxidation or carbon loss in 19 days after moldboard plowing was greater than the carbon contained in the stems, leaves, chaff, and roots of the previous wheat crop. Oxidation rate of organic matter from the no-till area was about 15 percent of that from the moldboard plowed area. Lamb et al. (1985) measured soil organic nitrogen losses in the top 12 inches of a soil that had been in native grass and was then cropped to winter wheat for 12 yr in a wheat-fallow system. Nitrogen loss, expressed as a percent of the nitrogen in the native grass soil, was 3 percent for no-till, 8 percent for stubble mulch, and 19 percent for plowed (black fallow).

Evaluation of organic carbon and nitrogen levels after 10 yr of no-till or conventionally tilled corn production in a Kentucky soil that had previously been in bluegrass sod showed approximately twice the carbon and nitrogen amounts in the surface soil layer of no-till (Blevins et al. 1983).

Following development of improved structure during 10 yr of undisturbed grass, as the transition is made to cropping systems, it is obvious that no-till management, by leaving the soil intact, causes less immediate disruption of the improved structure than conventional tillage. Chan and Mead (1989) measured water-transmitting macropores in a permanent pasture that had been lightly grazed. They found that cultivating to a depth of 4 inches for 4 yr completely disrupted the macropore structure, resulting in increased water runoff by reducing preferential flow within the macropore network and altering the pathway of infiltrated water movement. In contrast, the macropore system remained intact with no-till crop production.

In most cropping situations (no-till or conventional tillage) used after grass, the carbon input from root systems of the new crop will be less than that from the roots of the grass. Consequently, some loss of soil structural stability over time should be expected. The exact extent to which no-till can prolong the benefits of grass sod has not yet been determined. However, no-till systems implemented into tilled fields significantly improve soil surface characteristics when abundant residues are produced. This improvement is likely to lead to better infiltration and reduced erosion. Provision of optimum crop nutrients and the use of cover crops with no-till allows additional residue production and carbon input into the soil. A study in Kentucky found that organic carbon content of a soil that had previously been degraded by tillage was restored to near the same level as that of adjacent long-term bluegrass sod after 20 yr of cropping fertilized no-till corn with a rye winter cover crop (Ismail et al. 1994).

Conversion from conventional-till to no-till management systems has increased soil organic matter content and improved soil structure in soils that are low in organic matter or poorly structured; however, the structural improvements achieved during 3 yr of no-till can be eliminated with one moldboard plowing (Kladivko et al. 1986). These improvements in soil structure with no-till are not obtained immediately. As discussed in chapter 18, several years are often required before significant soil structural improvements can be documented. Soil erosion from either wind or water is reduced with the onset of no-till management simply because crop residues on the soil surface protect the soil from erosive forces. Water runoff is generally reduced when the management is changed from conventional tillage to no-till, but not always.

The CRP lands present many opportunities to initiate no-till in a situation where soil organic matter contents, soil structure, and infiltration rates have already been improved.

In eastern South Dakota on land that had been in an alfalfa-bromegrass sod for 6 yr, Lindstrom et al. (1994) initiated moldboard plow, chisel plow, and no-till corn production systems and obtained similar yields from all systems. In the 4th year of production, immediately after planting, artificial rainfall was applied at a rate of 2.5 inches/ hr for 1 hr on each of 2 consecutive days to each management system and on adjacent undisturbed alfalfa-bromegrass sod. No water runoff or soil loss occurred from the areas that were still in the sod or from the areas that had been in no-till corn production. An average of 49 percent of the water applied to the crops in the moldboard plow tillage system and 34 percent of that applied to the crop in the chisel plow tillage systems was lost to runoff. Soil loss from the moldboard plow systems was 11.8 tons/acre and 2.4 tons/acre for the chisel plow systems.

In the northern Corn Belt, conversion to no-till management from conventional tillage crop production systems has in some cases resulted in at least temporary decreases in infiltration (Lindstrom et al. 1981, Mueller et al. 1984). However, no-till row crop production systems following sod (in the Lindstrom et al. 1994 study) sustained much higher rates of infiltration as compared to the tilled systems following sod. The improvement in organic matter, soil structure, and infiltration that occurred under the 6 yr of brome-alfalfa growth was maintained with no-till into the fourth cropping season with no indication of soil degradation from the continued no-till cropping. The no-till system sustained and promoted soil macropores that extended from the surface to deep within the root zone and that were open to the atmosphere and protected by residue cover. These macropores resulted in high infiltration rates, reduced runoff, and subsequently reduced soil loss.

Sorghum yields in the panhandle of Texas in 1993 were much higher for a no-till crop after grass sod than they were for sorghum on soil prepared by moldboard plowing of the same grass sod (Unger, personal communication 1994). Yields under chisel plowing were intermediate. The primary factor responsible for increased yield under no-till was increased water-use efficiency. The no-till production system had no runoff and less soil water loss early in the growing season from evaporation and did not suffer as severely from water deficit at the critical period of flowering and grain fill as did the tilled treatments. A similar study in Colorado (Anderson, personal communication 1994) resulted in lower yields with no-till wheat production compared to where one undercutting tillage pass was used to help kill the grass. This reduced yield under no-till was associated with poor chemical control of the grass species resulting from the grass being under moisture stress when the herbicides were applied. The extreme competition for water in these semiarid areas emphasizes the importance of obtaining a good kill of the grass.

Two of the primary prerequisites for achieving a cost-effective no-till system following a CRP grass crop are to completely kill the grass and to allow sufficient water in the soil to accumulate for germination and sustenance of the new crop. If the new crop is to be planted in the spring, the grass must be killed in the previous fall or sooner depending on when dormancy occurs in the grass (Smith et al. 1992). Systemic herbicides can be used to obtain a good kill of the grass after the grass has been cut and begins vigorous regrowth. However, if the grass is dormant or under stress, such as may occur in regions where water is limiting in the summer and fall, then a systemic herbicide will give poor control. In areas where water is limited, the grass must be killed by earlier application of the herbicide before water stress induces dormancy or by tillage.

In situations where cool- and warm-season grass species are growing together in the CRP land, two applications of a systemic herbicide may be needed to avoid dormant periods of the different grasses.

Recognizing the need of farmers growing winter wheat to plant in the fall and the need for some land preparation before the wheat is seeded, the current rules of the CRP contracts allow farmers to begin such preparation, including tillage up to 3 mo prior to the October 1 release of such lands. If tillage (which buries the residues and disrupts and displaces the sod fabric) takes place, it will expose the soil to erosion and promote rapid decreases in organic matter and infiltration. However, if the needed killing of the grass is accomplished with an herbicide, the grass residues and sod will remain in place and protect the soil from erosion during the period when the soil is accumulating the water needed to germinate the seed and facilitate the growth of the following crop. Many studies have shown that the slowly decaying residues and sod will keep infiltration rates high and control erosion for at least a year following killing of the grass.

Farmers in arid regions may need to apply herbicides even earlier than 3 mo prior to October 1 in order to establish a no-till winter crop. As discussed earlier, they are likely to need to apply the first application in the early spring before the grass becomes water stressed. As long as the residues of the dead grass are left on the surface, this process should meet the objectives of the CRP contract, which require the farmer to maintain a protective cover on the soil and maintain production capability of the soil. However, CRP rulemakers have not yet, at this writing, granted permission for such an early application, and therefore this transition from CRP to no-till may not be possible in arid regions of the Great Plains without losing a year of production. Producers should check with their local SCS office to obtain the most recent information on when herbicides can be used on CRP acres during the last year of the contract.

One challenge that may occur when planting on no-till CRP land is how to deal with established burrowing animals and the damage that they may have caused during the 10-yr period of grass. They may leave the soil surface quite rough (Kalisz and Stone 1984). The tendency would be to moldboard plow the area before starting no-till. In extreme situations this may be required. However, normally tillage is not needed. Once the grass is killed and a crop has been planted, the food source is removed, the animals disappear, and the mounds tend to level within the year.

Nitrogen management on no-tilled former CRP lands also needs special attention because of changes in nitrogen mineralization patterns (Wood et al. 1991a, 1991b; Lamb et al. 1985). As tillage is imposed on sod, a flush of microbial oxidation and mineralization of organic nitrogen may occur. As tillage intensity is reduced, microbial oxidation of organic matter decreases and more of the organic nitrogen is retained in the soil organic matter. Soil testing is critical and the subsequent soil fertility recommendation must take into account the effects of the 10-yr period of grass and lack of a primary tillage operation. No-till into sod will initially require higher nitrogen rates than if the field was moldboard plowed (Thomas et al. 1973) because the plowing accelerates the biological decomposition of the organic matter and mineralization of its nitrogen.

Design of No-Till Systems

No-till systems must be designed according to the unique conditions of the region and the specific needs of the individual producer. Therefore it is not possible to design a no-till management system that can be applied at all locations across the United States or even within a single region. A successful no-till system must be developed from a whole-system point of view. Three things that need to be considered when designing a no-till system are rotation, sanitation, and competition to help control weeds, insects, and pathogens (Beck and Doerr 1990). Although the specific cultural practices required for each region and farm are likely to vary depending on climate, crop, and local markets, these three broad-based principles are common t the successful establishment of no-till crops. Other chap in this publication provide additional details on how to no-till and other types of crop residue management to specific soil, climate, and crop situations.

Sanitation involves practices that reduce the movement and spread of pests (weeds, diseases, insects) into a field. An example is the prevention of perennials from producing seed in the field borders by mowing. Another is the use of disease-free seed. The importance of following sanitation practices is more critical in no-till systems because they don't involve tillage, which can help reduce population levels of some pests.

Rotation is especially critical to a properly designed no-till system. Rotation can be beneficial in controlling weeds, disease, and insects by breaking life cycles that are dependent on compatible crops or by increasing the competitive pressure on a pest during a part of the rotation. An example is the use of a corn-small grain-soybean rotation to protect against corn rootworm infestations with extended diapause. The use of rotations in no-till generally helps create a stable, low-maintenance cropping system. The design of rotations should optimize the cropping sequence to control diseases, weeds, and insects and to provide adequate soil temperature at planting, seed zone moisture content, residue cover for erosion control, and labor and equipment utilization.

As a field comes out of grass sod into crop production, the rotation principle can be applied immediately by choosing a broadleaf species (that is, soybeans, peas, lentils, or flax) as the first crop. These crops will not generally succumb to or be a host for diseases that may have infected the grasses and will make weeds, including escaped grass, easier to control than if a small-grain crop was grown. An additional benefit associated with the use of legumes as a first crop is that their growth will not be appreciably restricted if the rapidly decaying grass depletes the soil nitrate supply.

Competition involves the ability of the crop to out compete weeds for light, water, and nutrients. An example of favoring a crop in such competition is the use of narrow row spacing to achieve earlier crop canopy cover. Cover crops may also be used in the more humid regions of the United States to compete with weeds, add nitrogen, and protect the soil during periods when cash crops are not growing.

No-till equipment has been designed for most crops. Care still needs to be used in no-till equipment selection to ensure that approved methods of chemical application are compatible with the equipment selected. Also equipment modifications may need to be made regionally depending on climate and soil-specific problems. For example, in the northern parts of the Corn Belt and the Cotton Belt, row-clearing attachments may be needed to remove some of the residue off of the row area. Removing some residue allows soil to warm up so that seed emergence is improved, especially in poorly to somewhat poorly drained areas.

Other aspects that should be included in the design of a no-till system include equipment use, livestock needs, personal preferences of the producer, cash-flow requirements, market availability, predictable climatic patterns, proximity of the water table to the surface, soil fertility, and risk management. Planners of no-till should study management practices and equipment that are adapted to the region and they must develop practices and modify equipment to adapt to the unique characteristics of their individual sites.

Conservation Measures for Residue-Deficient Crops

When the primary cash crop suited to the area is a residue-deficient crop such as sunflower and when wind erosion potential is the cause of the highly erodible land designation, there may not be sufficient residue during the year following the cash crop to provide the mandated erosion control. Grass hedges, which reduce wind velocity at the soil surface (Aase and Siddoway 1976) and trap stray soil particles that have been mobilized by the wind, can often complement no-till management to achieve the needed erosion control. To be most effective the grass in these hedges should be stiff stemmed and tall because the downwind distance to which they cause significant reductions in wind velocity is limited to about ten times their height. In the few cases where the grass planted into the CRP lands has tall and stiff stems (for example, switch grass or tall wheat grass), the needed hedges can be achieved by leaving living strips of grass 2- or 3-feet wide between strips of planned, cropped area that are about ten times the height of the grass.

If grass on the CRP land is not sufficiently stiff and tall enough to provide the needed reduction in wind velocity, CRP rules allow improvements of the cover during the contract period. Since most perennial grass species require about 2 yr to reach maximum stature and extend their roots below those of annual crops, rows of tall grass for hedges will be better prepared to thrive and to protect the cropped area if they are planted a year or two before crops will be planted. This can be accomplished by killing the grass strips within the CRP land with herbicides and planting them with the desired tall, stiff-stemmed grasses. When these hedges have reached the desired height and the CRP contract rules allow killing the grass in preparation for planting the crop, the short grasses in the planned crop strips between the hedges can be killed. To avoid the potential for being considered in violation of CRP rules, discuss your plans for installing tall grass hedges in CRP lands with your SCS District Conservationist before killing grass during the CRP period. Costs of this additional improvement of CRP lands to provide tall grass hedges for erosion control of subsequent crop lands cannot be shared by the CRP. However, since less than 10 percent of the area is in the grass hedges, the cost for herbicide and seed is small.

Benefits of grass hedges for control of both wind and water erosion are discussed in chapter 16. While game birds have been observed nesting and overwintering in tall grass hedges, there has been no systematic evaluation of the effects of these hedges on bird populations.

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18 Long-Term Effects of Tillage and Crop Residue Management

W.C. Moldenhauer, W.D. Kemper, and A.L. Black

The Beginnings of Soil Degradation

When Europeans arrived in America, they found soils that were a result of climate and vegetation interacting with the geologic minerals. Leaves and other residues fell to the ground and decayed, and part of their decomposition products leached into the soil. Roots grew, died, and decayed, also contributing to building the organic matter and associated elements that nurtured the natural successions of plants. Among these plants were legumes that provided photosynthate to bacteria infecting their roots. These bacteria were able to take nitrogen out of the air, fix it into ammonium, and share it with their host plants. Primarily as a result of these legumes, about 6 percent of the residual organic matter in soils is nitrogen. Other plant nutrients extracted from the soil and air and incorporated into the plants also became part of this soil organic matter. While most of the native Americans were crop growers, they were few in number. Their methods of crop production involved little tillage. Competing weeds were removed largely by hand.

Friendly natives taught the newly arrived Europeans how to grow corn in the early part of the 17th century. With their iron mattocks and hoes, the Europeans were able to control weed growth more efficiently than the natives. Within a few years corn was the staple of their diet, and they were growing enough corn to trade it for animal furs. Arrival of draft animals, cultivators, and plows gave the Europeans additional ability to control weeds. These implements also stirred and aerated the soil, buried crop residues, and stimulated microbial activity, which increased the breakdown of the residual organic matter, liberating its nutrients for use by the crops. Since there were no commercial fertilizers, this accelerated decomposition of organic matter was the primary source of plant nutrients in those early years. The moldboard plow, which turned the soil over completely and buried practically all of the crop residue, became the most popular implement for primary tillage.

Complete burial of the crop residue and decreasing residual organic matter exposed soils to the beating action of raindrops, which destroyed soil aggregates, filled the large pores, and reduced infiltration, causing runoff and erosion. Erosion by runoff water carried away substantial portions of the topsoil in the eastern and southern portions of the country where rainfall rates were high. In the more arid western Plains, burial of plant residues and subsequent beating from rain created smooth surfaces along which the wind blew the sand grains until they literally sandblasted the soil, enabling the wind to blow away major portions of our topsoils.

Early in the 20th century concerned farmers and government officials recognized the rapid degradation of our soils from erosion and initiated research and plans to reduce erosion. In the 1920's and 1930's, rotations, strip cropping, and mulch tillage were evaluated. These techniques involved blades that sliced under the surface and killed weeds but left most of the wheat stubble on the surface. They obviously helped reduce wind and water erosion. It took longer to observe their effects on soil organic matter content and fertility. Long-term studies were initiated at several locations across the country. At Urbana, IL, the Morrow plots were established in 1876 to determine long-term effects of various kinds of cropping. They indicate that the soil organic matter level was about 6.4 percent when European Americans began tilling them. Continuous corn, involving plowing each year, reduced the organic matter content to less than 3 percent (fig. 3). The best rotations reduced the rate of organic matter depletion, and legumes in those rotations helped maintain soil fertility; however, levels of organic matter still continued to decline as long as plowing continued.

At Pendleton, OR, the residual organic matter content in soil under grass was also reduced under moldboard plowing, accelerating runoff, erosion, and loss of fertility. Consequently, in 1929, researchers began evaluating a series of crop residue management treatments, ranging from burning the residues to plowing 10 tons of manure plus the crop residues into the soil each growing season. Refraining from burning slowed the decline of residual organic matter, and during the first 20 yr the heavy manure addition each year seemed to slightly increase the organic matter content (fig. 4). However, even with 11–12 tons of organic residue plowed into the soil each growing season, residual organic matter content has not increased during the past 40 yr (Rasmussen et al. 1989).

Reicosky and Lindstrom (1993) measured the carbon dioxide given off in fields for 19 days after wheat stubble was moldboard plowed, chisel plowed, disked, or left standing with no-tillage. As shown in figure 5, the amount of carbon oxidized was greatest in fields that were moldboard plowed. In 19 days as much carbon was oxidized as had been photosynthesized and incorporated into the residues and roots during the whole growing season. A large portion of the crop residue was not completely decomposed at the time. Consequently, it appears that easily decomposable portions of the fresh residue provided food to generate high microbial populations, which found access to residual organic matter in the plowed and highly aerated soil and oxidized substantial amounts of it out of the soil.

Other types of tillage, resulted in lower biological oxidation rates than moldboard plowing (fig. 5). Their use is helping slow the rate at which residual organic matter is being oxidized out of our soils. However, during the 19-day study, oxidation of organic matter from all of the tillage treatments was much more than that from the no-till treatment.

Effects of Reducing Tillage on Residual Organic Matter

Development of wide v-blade sweeps, rod weeders, and other equipment that disrupt the soil and undercut weeds while leaving most of the crop residue on the surface helped control erosion (Lindstrom et al. 1974). As relatively low-cost fertilizers became available in the early 1960's, however, it was no longer necessary to till soils and oxidize organic matter to release needed nutrients. Development of herbicides provided an alternative to tillage for weed control. As conservation-minded researchers and farmers saw the improved erosion control from leaving residues on the surface, they used these alternatives and reduced tillage. Some of them reasoned that growth of grain crops was now possible in systems more similar to those in natural ecosystems where there is no tillage.

In these natural systems when vegetative growth is good and burning does not occur, the soils generally have continuous cover and protection from the forces of wind and water. The major obstacle remaining was getting seed through the surface residues and into the soil. Equipment companies helped develop coulters, seed placement devices, and press wheels that cut through the residues without disturbing them appreciably and pressed seed into good contact with the soil. Development of no-till drills and seeders provided an alternative to seedbed preparation, the other major purpose of tillage. With these alternatives available, thousands of fields were soon managed without tillage.

The erosion control benefits of no-tillage were immediately obvious. Researchers documented that no-till reduced erosion to less than 20 percent of that occurring under moldboard plowing systems or in many cases eliminated it completely. By removing crop residues from some of their no-till plots and observing erosion during rainstorms, they found that absence of tillage, in addition to keeping protective residues on the surface, leaves the soil more cohesive and more resistant to the erosive forces of water. Measurements in laboratories show that bonding forces between soil particles decrease with tillage and increase with time following tillage. Root fabric and the high residual organic matter content that develops in the immediate surface under no-till reduce slaking and disintegration of aggregates when they are wetted.

In the past, scientists felt that incorporating crop residues into the soil was the way to get organic matter into the soils where it could become part of the residual organic matter. Reicosky and Lindstrom (1993) showed this intuitive feeling was wrong. In fact, incorporating crops residues into the soil by moldboard plowing accelerates the rate of oxidation of both the crop residues and the residual organic matter, as discussed previously.

Farmers practicing no-till management are noticing their soils becoming darker. In Ohio, Georgia, Alabama, and Colorado measurements showed residual organic matter in no-till soils to be increasing. This increase was greatest in the surface 2 inches, the area most important for reducing slaking and surface sealing. However, increased organic matter has been observed to depths of 6 inches in some fields where no-till has been used for at least 10 yr (fig. 6). Since tillage is not being used to incorporate the organic matter, one wonders how the organic matter gets that deep. Water passing through organic residues into soils often carries over 100 ppm of dissolved organic matter, so 3 acre ft of water leaching through the residue could carry 1,000 lb/acre of organic matter into the soil. Decaying roots and exudates from roots also add organic matter at a rate of 1,000–2,000 lb/acre/yr. A major portion of this organic matter is used as an energy source by microorganisms, but much of it is incorporated in their tissues and becomes part of the residual organic matter. Earthworms and burrowing animals and insects also help mix organic matter from the surface crop residues into the soil.

Effects of Increasing Surface Residues on Residual Organic Matter

Measurements of residual organic matter in soils during 10 or more years of no-till management indicate increases ranging from 200 to 1,500 lb/acre/yr. These rates depend on how much crop residue is left on the surface. The highest rates occur where crop residues were augmented with winter cover crops left on the surface. The lower rates were from dry, warm regions where the amount of crop residues was limited and high temperatures caused rapid biological oxidation of the organic matter.

In areas where residual organic matter is low, organic wastes such as paper and manure have been placed on the soil surface or plowed into the soil to help increase the organic matter. The greatest sustained increases are resulting from leaving the organic wastes on the surface (Lu et al. 1994a, 1994b).

Reduction of tillage increases the amounts of organic residues on soil surfaces, decreases the biological oxidation rates of residual organic matter, and reduces soil erosion, all of which cause net increases in residual soil organic matter. No-tillage and reduced tillage not only can conserve our soils, they can also enhance them so they will be able to help sustain the world's growing population.

Effects of Leaving Crop Residue on the Surface

On Soil Fertility, pH, and Rooting Depth

One early concern about no-tillage was getting fertilizer and lime from the surface down to the crop roots. To some extent feeder roots solved this problem by coming nearer to the surface where the soil was moister because crop residues reduced evaporation.

Phosphorus particularly was also expected to be a problem because it is normally tightly adsorbed and relatively immobile in soils. However, as Kunishi et al. (1986) found, it apparently forms complexes with organic matter when left on surface residues that leach into the underlying soil where they are readily available to feeder roots. Through mycorrhiza—the beneficial association of fungal mycelium with the roots of a plant—fungi extend their slim hyphae into the soil and allow plants to draw phosphate from those parts of the soil their roots cannot directly reach. More of these hyphal conduits remain intact when tillage does not occur. Crop roots in no-till soil tend to follow root channels of the previous crop; this enables the supplemental hyphal system to tie in more quickly, which helps the roots extract water, phosphorus, zinc, and many other elements from the soil.

In the drier regions of the United States where crop yields depend on stored soil water, proper residue management can increase soil-water supplies sufficiently to reduce the use of summer fallow. In order to take advantage of the additional water conserved, producers must change from crop-fallow to extended crop rotations with reduced use of fallow. By eliminating the practice of tillage-fallow, the continued loss of soil organic matter from biological oxidation is reduced. Initially, annual cropping systems with high crop residues will need additional fertilizer nitrogen to optimize use of the additional soil water conserved and the growing-season precipitation. However, in annual cropping systems under minimum- or no-tillage, the quantity of nitrogen fertilizer needed may decrease after several years as the amount of nitrogen coming out of the residual organic matter to the crops comes closer to equaling the amount going in.

On Infiltration, Evaporation, and Water-Use Efficiency

The most direct and measurable effect of keeping crop residues on the soil surface is improving the water-use efficiency of acid and calcareous soils. In many areas the increases in infiltration rate and decreases in evaporation occur within a year or two, as discussed in previous chapters. However, in soils where earthworm populations were decimated by intense cultivation or harmful pesticides it may take many years to bring their numbers back so their burrows to the surface contribute significantly to infiltration.

In a series of small watersheds near Coshocton, OH, it took earthworms 6 or 7 yr to return in large numbers after beginning no-till management (fig. 7). Results were obtained based on measurements of pores larger than 0.5 mm at the soil surface; earthworms and recent cultivation are commonly responsible for such large pores. Following cessation of cultivation, the percentage of the surface occupied by these large pores declined for 5 yr. Only when the earthworms returned in large numbers were the large pores furnished that contribute to rapid entry of water in this soil.

Return of worms has been hastened by collecting buckets of them from lawns and edges of rural roads during or immediately following rains and depositing them in groups of four or five in new no-till fields. They will invade a soil at a rate of about 50 ft/yr when conditions are good for their growth. However, their lack of a specific urinary tract leaves urea on their skins, which hydrolyzes to ammonia and irritates them. Consequently, they are attracted to moist soils where they can quickly rub off the urea and ammonium and to the surface during rainfall events where the rain washes them off. Their tendency to come to the surface during rainfall events contributes to their migration during runoff events, when they float downhill. On cloudy days when canopy cover was reasonably complete and at night, earthworms have been seen floating in tailwater out of furrow-irrigated fields in Idaho at rates of up to 50/hr/furrow. In runoff plots at Kingdom City, MO, as many as 900 earthworms washed off a single plot in a single rainfall event. While average rates of downstream transfer are generally lower than those given in these examples, introducing worms on the higher portions of fields can significantly increase their rate of return to the whole field.

As soon as crop residues provide cover for most of the surface for a significant part of the year, they help reduce evaporation from the soil. Long-term no-till practitioners report that the amount of crop residue returned to the field per year increases with time for 10 or more years as crop yields increase. However, some long-term no-tillers note that large populations of night-crawler-type earthworms collect residues in their middens, especially after soybeans, causing a more-rapid-than-normal removal of cover from the soil. Fortunately, this process does not usually reduce cover until the crop canopy has already begun protecting the soil from the impact of raindrops. Even when lack of cover allows a major portion of the soil surface to seal, several earthworm middens or holes per square yard drain most water accumulating on the surface into the soil, minimizing runoff.

In the more arid regions of the Great Plains most of the soils do not remain wet enough to sustain significant populations of earthworms without irrigation.

On Crop Production

Factors that increase the units of crop produced per unit of precipitation include significant increases in infiltration, decreases in evaporation from soils, increased water-holding capacity, increased snow catch and deeper rooting associated with no-tillage, and retention of surface residues for extended periods.

Long-term trends in corn yield under no-till compared to tilled management (fig. 8) indicate that the benefits to production derived from long-term no-till are substantial.

High residual organic matter in soil also increases general fertility and productive capacity. In North Dakota, Bauer and Black (1994) quantified the value of soil organic matter to soil productivity on three sites. On average the presence of each ton of organic matter per acre increased the grain yield by about 20 lb/acre. If the loss of soil organic matter from erosion and tillage-accelerated oxidation is a ton per acre per year for 30 yr, then 30 tons of organic matter would be lost. The resulting productivity loss would be about 30 × 20 = 600 lb/acre or about 10 bu/acre.

Soil organic matter acts as a "bank" where nutrients may be deposited in times of surplus and withdrawn in times when rainfall or irrigation leaches out most of the soluble and mobile nutrients, especially nitrates. Prolonged nutrient deficiency can be alleviated with fertilizer nitrogen. Temporary nitrate deficiencies will not reduce crop growth nearly as much in soils with high organic matter content where microorganisms are slowly and continually drawing nitrogen "from the bank," making it available to roots.

Residual organic matter, which derives from plants, includes most of the elements essential for crop production, and its slow decay provides a limited but continuing source of these elements. Slow decomposition of this organic matter also furnishes a host of organic molecules or fragments that act as carriers, enabling micronutrients absorbed in the soil minerals to reach the roots. Unlike no-till, tillage accelerates the rate at which nutrients from crop residues and residual soil organic matter are mineralized or made available to crops. If the crop is not ready to use the nitrates, they are at risk of being leached out of the crop root zone by rain. Like stirring the coals, putting in kindling, and opening the draft of a wood stove, tillage accelerates the oxidation of organic matter, liberating its components quickly to the surrounding environment.

Organic matter also darkens soils. They appear dark because they are absorbing more of the sun's radiation, and soils that absorb more of the sun's radiation are warmer. Because crop residues reflect more of the radiation and insulate the cold soil from the warmer spring air, covered soils stay cooler, which decreases plant growth in the cool early spring but may be better for crops in the late spring or early summer if temperatures rise too high.

If there is good evidence that warmer soil temperatures in the early spring will increase yields, farmers can mount equipment on their tool bars to move residue off seed rows before or at planting time. Removal of the residue also permits continued use of conventional planters for those farmers who do not own no-till planters.

On Erosion Control

Residue cover achieves erosion control by (1) intercepting the impact of raindrops, slowing surface sealing, and sustaining higher infiltration; (2) causing water to pond on the surface, which causes wormholes and other micropores to become avenues for infiltration; (3) causing settlement of sediment in the temporarily ponded water; and (4) reducing or eliminating wind shear from reaching the soil surface and detaching particles. Refraining from tillage allows long-term mineralogical processes to strengthen moist soils with time in ways similar to the processes that strengthen concrete.

Research by Bauer and Black (1981) in the northern Great Plains compared the changes in soil organic matter and total soil nitrogen over a 25-yr period on four soil series where conventional tillage that buried the residue and stubble-mulch and minimum tillage were used. The minimum-tillage fields contained about 6,750 lb/acre more carbon (11,475 lb/acre more soil organic matter) and 711 lb/acre more nitrogen than the conventionally tilled fields. On average the minimum tillage conserved about 470 lb/acre/yr of soil organic matter and about 28 lb/acre/yr of soil nitrogen. These increases were probably a result of reduced rates of erosion and biological oxidation and increased production of residues from improved infiltration and less evaporation.

Reasons for Limited Tillage

Legitimate arguments for performing some tillage include the following:

- In some cases the cost of a nutrient form, such as the anhydrous form of ammonia, is sufficiently lower than the cost of another nitrogen fertilizer to economically justify the limited cultivation needed to incorporate the ammonia.

- Deep chiseling or paratilling of soils to help crop roots past restricting layers benefits yields in some areas.

- As mentioned, ridge- or row-till equipment can push residues off the planting strip for row crops, allowing the use of conventional planting equipment and warming the soil to accelerate early growth.

- In some special soils and when insufficient or very low amounts of crop residue are present, shallow tillage to a depth of 2–3 inches can break the capillary pore connections between the soil water and the surface. This operation saves stored water if performed before long, dry, hot summer fallow periods.

- During the initial 2 or 3 yr of no-till, before sufficient soil cohesion has developed to support equipment weight, the soil may become so compacted and rutted during harvest in wet weather that tillage is necessary to break up the compaction and smooth the surface.

Each farmer must balance these arguments for cultivation against the damage that tillage does in reducing residual organic matter and reversing the benefits of crop residue management. One of the most critical factors that needs to be examined is the degree to which tillage will destroy soil cohesion, crop residue cover, and erosion control as computed by Soil Conservation Service (SCS) guidelines and equations. The economic consequences of failure to be in conservation compliance will be devastating for most farmers enrolled in government programs. Consultation with SCS technicians may help farmers avoid both the loss of erosion control and crop support payments. One moldboard plowing can oxidize as much organic matter out of a soil as accumulated by 5–10 yr of high-residue no-till management. Other types of tillage that cause less oxidation should be considered when tillage is necessary.

Effects of Herbicides on the Environment

Concern has been expressed in some public sectors that long-term use of herbicides for weed control rather than tillage will add manufactured chemicals to our soil, air, and water, thereby degrading them. A broad survey by Bull et al. (1993) indicates that producers who grow corn use about equal amounts of herbicides whether on tilled or on no-till systems.

Most farmers recognize that herbicides are often the most cost-effective means to control weeds. In 1990 herbicide use on no-till soybeans averaged about 60 percent higher than that used on tilled soybeans; by 1992 no-till averaged about 20 percent more. Long-term no-tillers say they are using less herbicide than when they started and often even less than when they were tilling. Because adoption of no-till has been doubling about every 3 yr and only 25 percent of no-till farmers have a minimum of 6 yr with the system, we anticipate that the amounts of herbicides used in no-till farming will continue to decline.

A factor that plays a significant role in herbicide contamination of water is the use of soil-incorporated (preemergence) versus direct-contact (postemergence) herbicides. Preemergence herbicides are the more common choice of conventional tillers. And farmers are using some preemergence herbicides in granular form in minimum-tillage systems. Here's an example of one technique. More than 50 percent of the cereal grain residue can be maintained after seeding sunflowers in annual cropping systems by early spring use of an undercutter with 32-inch wide sweeps and a front-mounted granular applicator to apply and incorporate a preemergence herbicide followed by a second application of herbicide near seeding. On the other hand many of the postemergence herbicides, which are becoming the major choice in no-till management, are sprayed directly on the weeds, strongly adsorb (adhere) to soil if they miss their target, and rapidly hydrolyze or biologically degrade when they contact the soil.

The use of minimum-tillage and no-tillage systems can benefit soil-water conservation sufficiently to recommend a change away from traditional crop-fallow systems, which produce one crop in 2 yr, to more intensive annual crop rotations. In a spring wheat-winter wheat-sunflower rotation, only one herbicide is used per crop each year, as opposed to the average 4–6 applications per year used in minimum- and no-till crop-fallow systems.

Reduced tillage keeps topsoil on the land and out of air, streambeds, reservoirs, and lakes. Where no-till increases, better infiltration rates reduce flood damage, and increased groundwater recharge and base stream flows improve the environment. In monitored watersheds, where surface sealing from conventional tillage caused 10–30 percent of the precipitation to run off, long-term no-till often reduces runoff to negligible levels.

As water runs off, it carries feces from domestic and wild animals, disease organisms, and a host of organic compounds over 99 percent of which are of natural origin and less than 1 percent of which are of manufactured origin. Surface runoff that enters reservoirs is so heavily laden with contaminants that standard rapid filtration cannot remove them all. Chlorination is commonly required to kill the pathogens before water can be used for drinking, but chlorination of humic acids and natural organic compounds can increase their carcinogenicity. When reduced tillage enables all precipitation to enter the soil, pathogens and other organic compounds filter out as the water percolates slowly down so that the water which enters aquifers is generally of good drinking quality.

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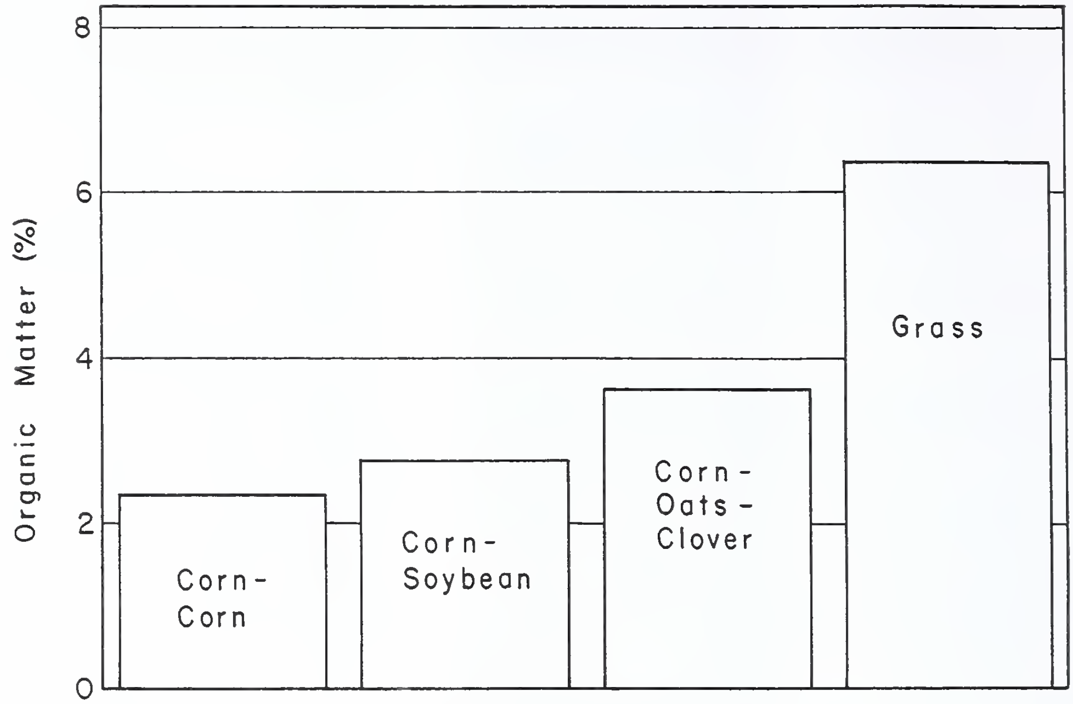

Figure 3. Percentage of organic matter in plowed soils after more than 100 yr in various rotations compared with percentage in untilled soil still in grass. Source: Odell et al. (1984).

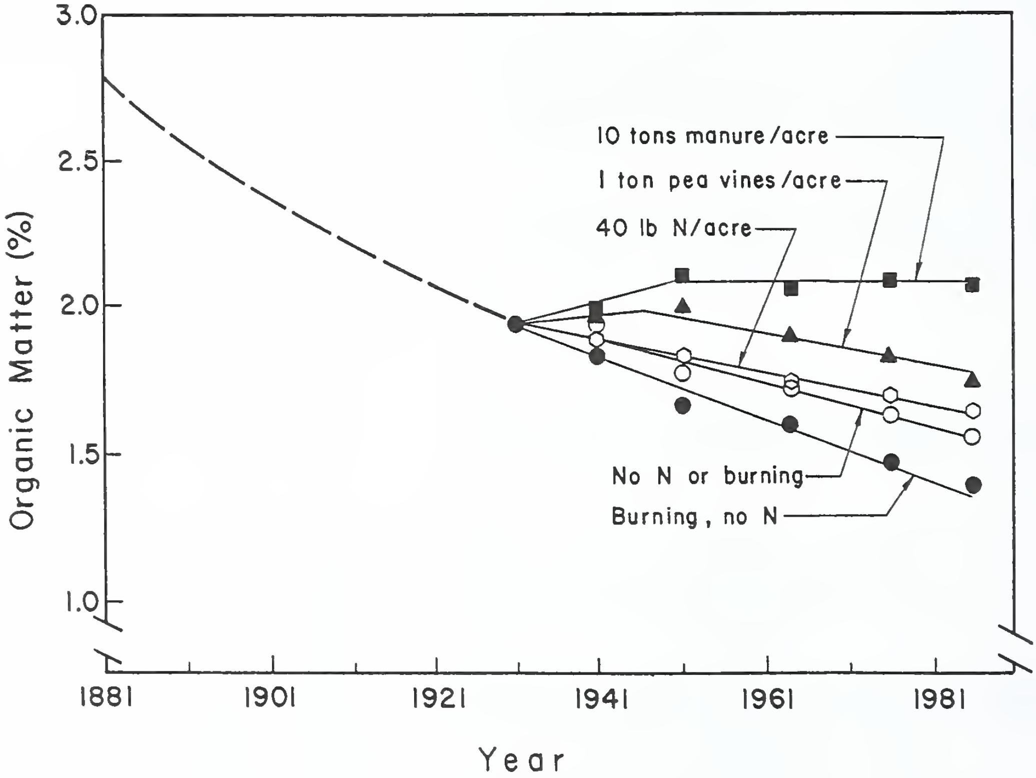

Figure 4. The effect of management practices on long-term changes in organic matter in the top 30 cm of a Haploxeroll soil in Oregon. Source: Rasmussen et al. (1989).

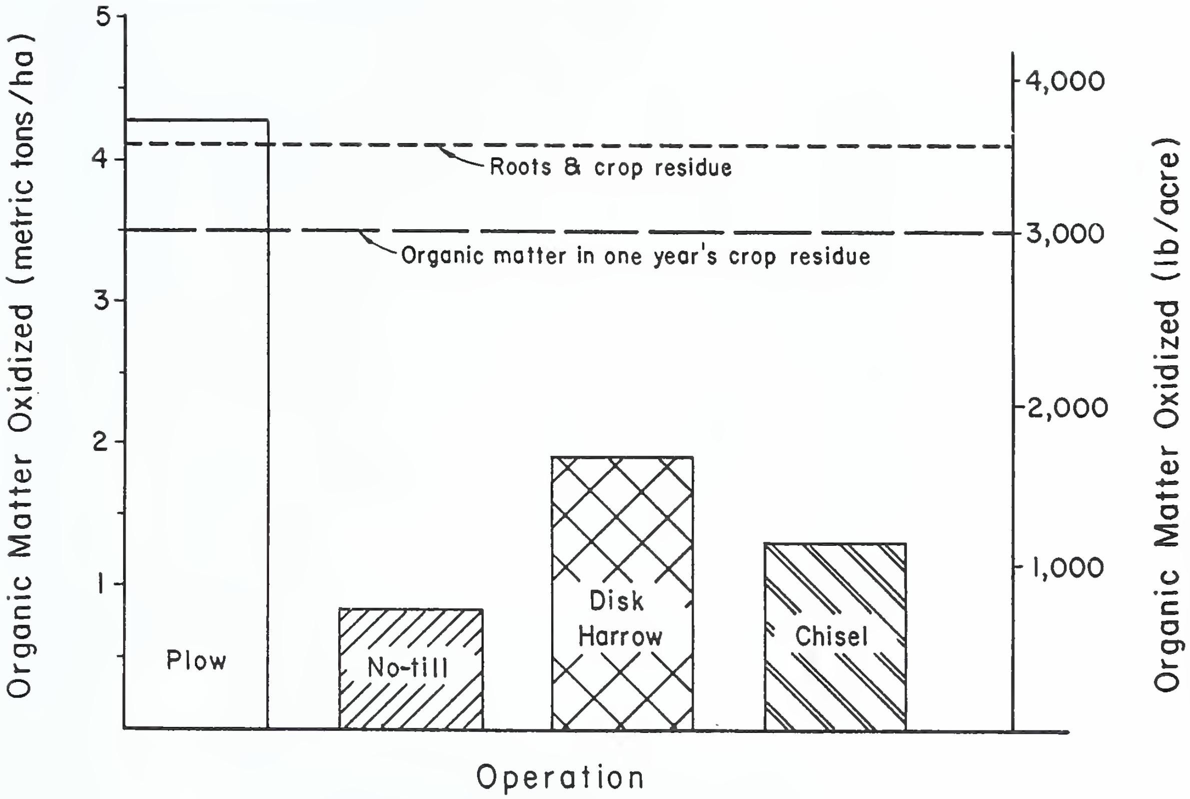

Figure 5. Organic matter oxidized in 19 days in September following various tillage operations on wheat stubble in Morris, MN. Source: Reicosky and Lindstrom (1993).

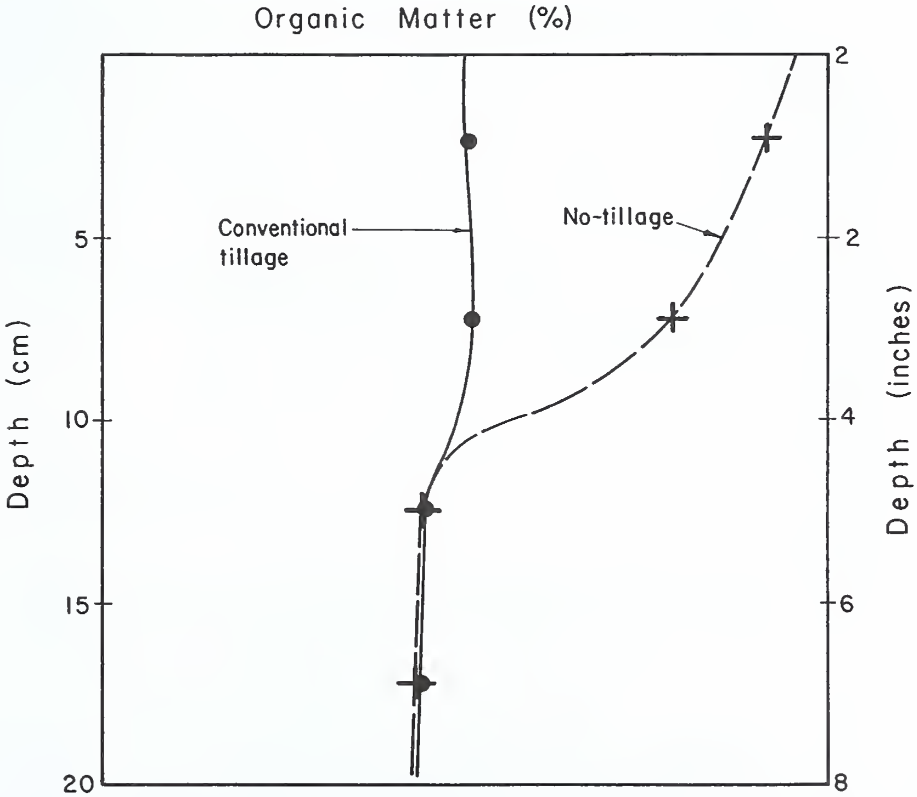

Figure 6. Comparison of organic matter content at various soil depths after 10 yr of a conventionally tilled and a no-tilled corn-wheat-soybean-wheat rotation in Crossville, AL. Source: Edwards et al. (1992).

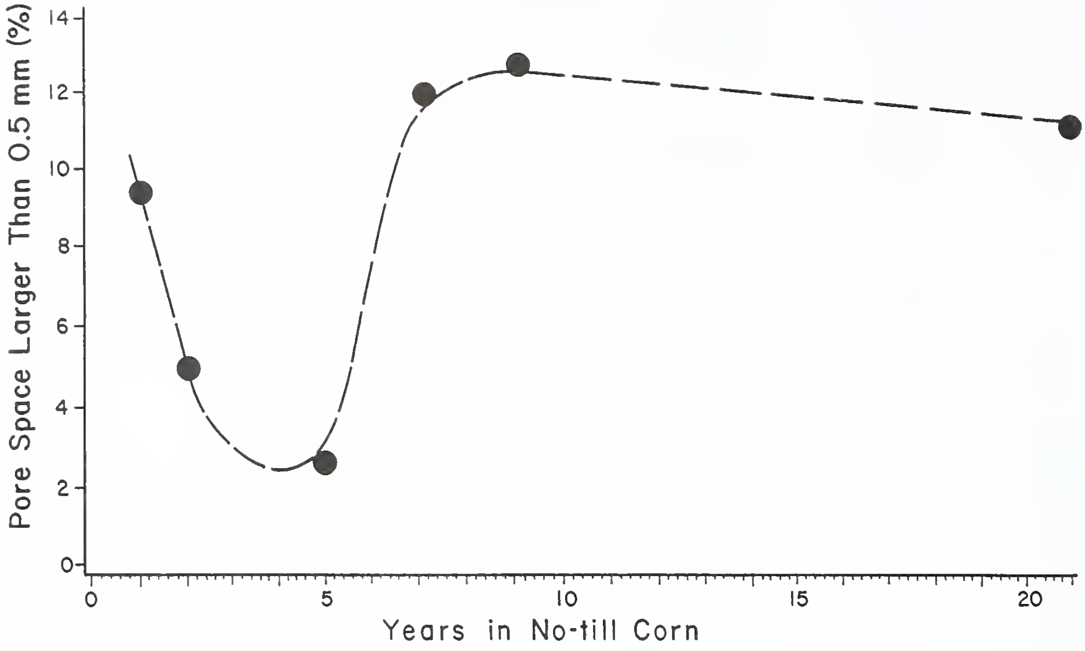

Figure 7. Changes in surface pores larger than 0.5 mm diameter after beginning no-till management in Coshocton, OH. Source: Norton and Schroeder (1987).

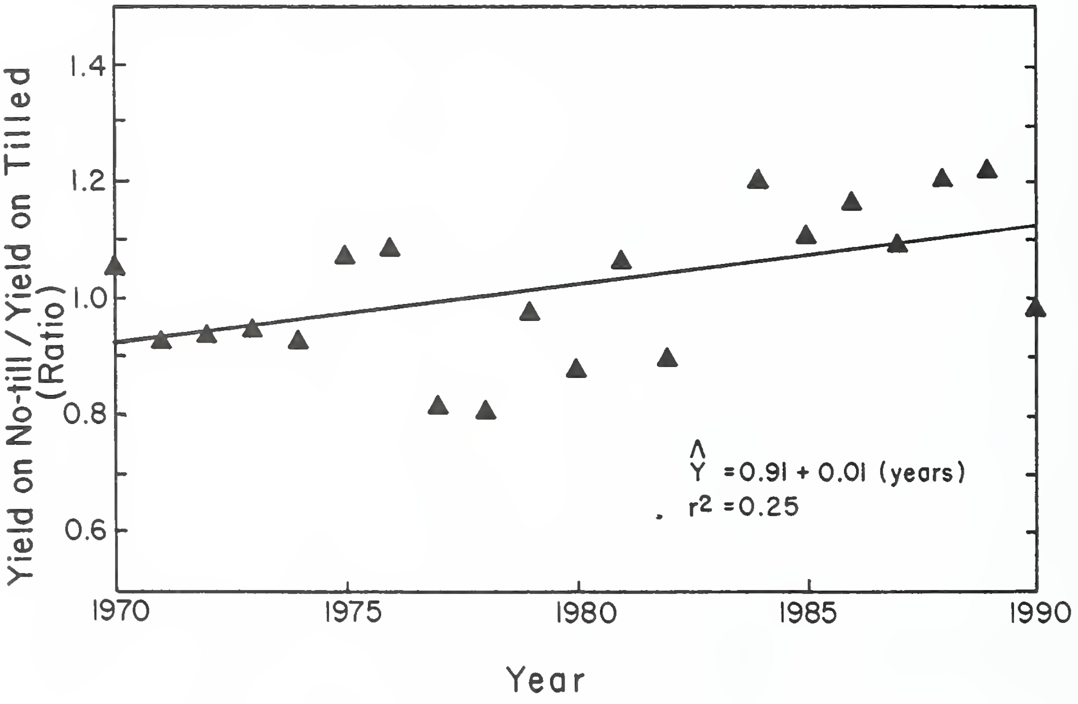

Figure 8. Long-term trends in corn yields under no-till compared to tilled management. Source: Ismail et al. (1994).

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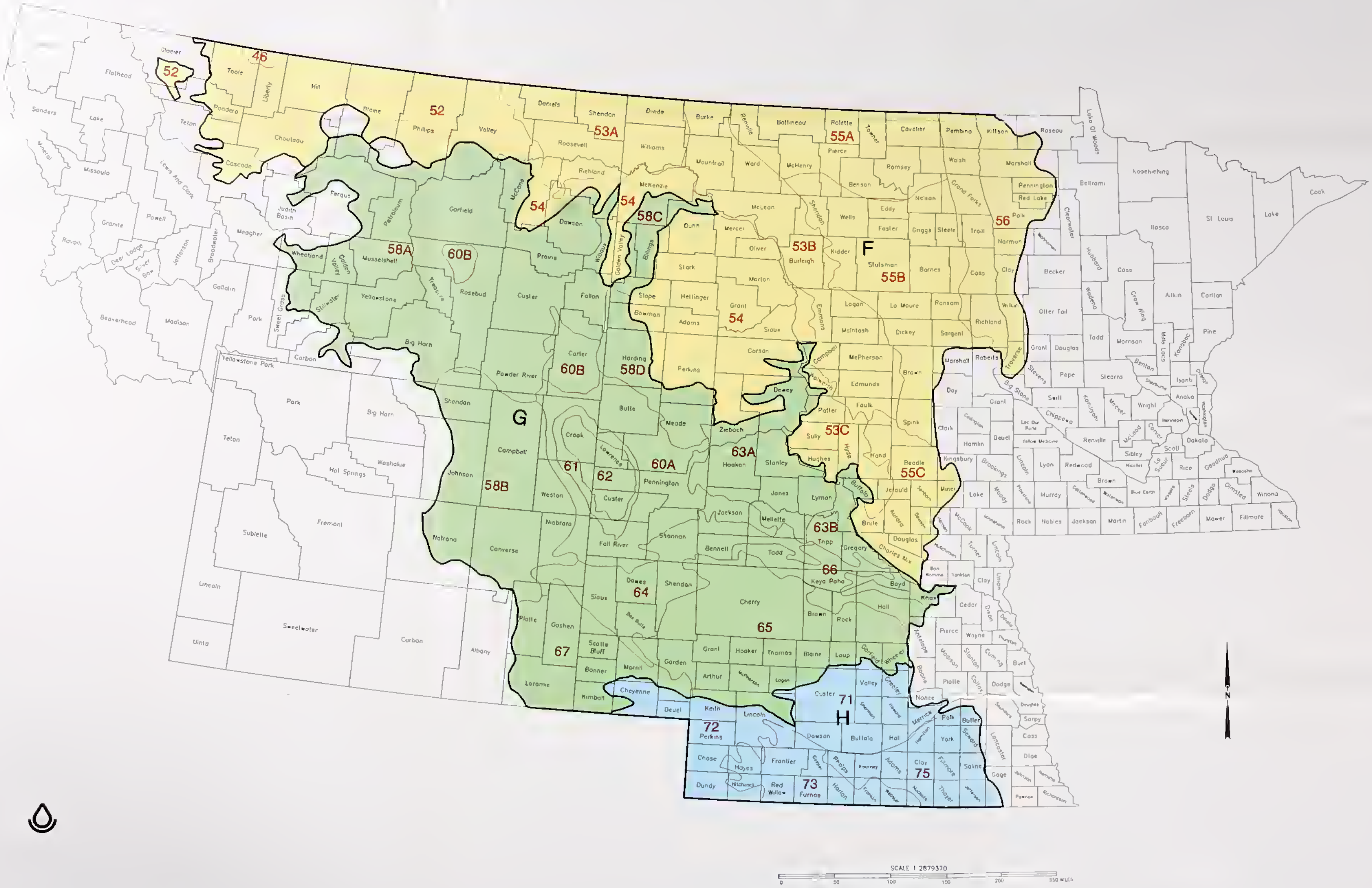
MAJOR LAND RESOURCE AREAS OF THE NORTHERN GREAT PLAINS
(F, G - North of CO & WY line, H - North of KS & NE line)



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